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A Geographic Information System for Risk Assessment of Fasciola Hepatica in Cattle.

Stanley Harland Zukowski

Louisiana State University and Agricultural & Mechanical College

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A geographic information system for risk assessment of *Fasciola hepatica* in cattle

Zukowski, Stanley Harland, Ph.D.

The Louisiana State University and Agricultural and Mechanical Col., 1990

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A GEOGRAPHIC INFORMATION SYSTEM FOR
RISK ASSESSMENT OF Fasciola hepatica IN CATTLE

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
in
The Interdepartmental Program
in
Veterinary Medical Sciences

by
Stanley Harland Zukowski
B.S., United States Coast Guard Academy, 1973
D.V.M., Louisiana State University, 1984
December, 1990

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ABSTRACT

A geographic information system (GIS) was used to assemble and analyze data on the spatial distribution of habitat of the snail, Fossaria bulimoides, an intermediate host of Fasciola hepatica. A model of habitat was developed on a single 760ha farm on the Chenier Plain of southwestern Louisiana and extrapolated for testing on 12 other farms in a 29,000ha extended study area of the Chenier Plain region. Input maps were: 1) soil series (type), 2) fencelines, 3) F. bulimoides habitat, and 4) soil salinity. On the primary study farm, habitat was strongly associated with interfaces of marsh and chenier (relict beach) soils, more consistently along a chenier waveface than on the backslope. On the 12 new farms, 23 per cent of snail habitat was found on chenier-marsh interfaces, most of this along interfaces adjacent to relatively broad cheniers; 61% of snail habitat occurred within the Hackberry-Mermentau (Hm) complex of soil series on broad cheniers, above interfaces. The proportion of farm occupied by F. bulimoides habitat regressed significantly against the proportion of farm comprised of Hm soil ($p = 0.024$, $r^2 = 0.416$, slope = 0.165). Results indicate that a successful soil-based model for estimation of snail habitat distribution on the chenier plain region should include the area of soils of the Hackberry-Mermentau complex as well as the interfaces of marsh and cheniers.

Although snail habitat was localized to Hackberry-Mermentau soils and chenier-marsh interfaces on broad cheniers, no consistent relationship was shown in the present study between soils and fecal egg shedding by adult cattle on 10 farms.

INTRODUCTION

Fasciola hepatica is an important parasite of domestic ruminants, found around the world from tropical to arctic latitudes. Its distribution is notably patchy, dependent on landscape features and soils suitable for colonization by the snail intermediate host and on a climate regime favoring development of the snail and larval stages of the parasite. In most places, the severity of fascioliasis in a given year depends on climate events during the season of snail activity, so that epizootics occur sporadically. Production losses in sheep during severe epizootics can be spectacular, with high rates of death and debility. However, even more serious long-term economic effects are attributed to subclinical disease. These are insidious production losses such as reduced feed conversion and reproductive performance and depressed quantity and quality of wool production. Cattle experience similar serious production losses from subclinical disease, but seldom manifest the acute disease. Major advances in chemotherapy allow modulation of the most severe effects of the disease, but the persistence of the parasite (due mostly to the high reproductive potential of both fluke and snail) dictates continued emphasis on integrated control, with expanded research on ecology, epidemiology and immunology to achieve maximum economic benefit of control measures.

Recent advances in computer technology are being applied to elucidate the effects of ecological factors on epidemiology of

fascioliasis. A forecasting system has been developed to predict the severity of fascioliasis in Louisiana, based on the Thornthwaite water budget and the growing degree-day concept. As much as 100-fold differences in severity of fluke burdens can occur between years due to climatic factors alone.¹ An equal variation in severity between farms can occur in a given year due to variations in snail habitat extent and management factors not included in the climate forecast.² Malone and Craig proposed that a comprehensive model should consist of 4 elements: 1) the climate model of life cycle development; 2) an estimate of habitat-related individual farm risk; 3) management-related factors, including treatment history, herd age structure, forage availability, pasture rotation, etc.; and 4) an economic risk component, related to market conditions and cost-benefit analysis.³

This dissertation represents 3 studies directed toward development and verification of the second element, estimating the component of related individual farm risk of fascioliasis related to areal extent of snail habitat, by use of a geographic information system (GIS) that incorporates soil maps and field survey maps of snail habitat. It is presented in the form of manuscripts for submission for publication, as follows:

1. Method of development from soil and habitat maps of a GIS model depicting snail intermediate host habitat as bands along interfaces of certain soil series; extrapolation of the model to a larger area.

2. Survey of snail habitat on 12 farms to verify extrapolation, with sampling stratified according to model categories, noting modifications needed to improve the model.
3. Evaluation of the relationship of model snail habitat to bovine fecal shedding of Fasciola hepatica and Paramphistomum microbothrioides eggs, and the relationship between egg shedding for the 2 fluke species in herds without histories of recent treatment against F. hepatica.

LITERATURE REVIEW

The biotopes inhabited by lymnaeid snail intermediate hosts of trematodes have been characterized as unstable and low in diversity of species. These species (including the snails and extramammalian stages of trematodes) typically propagate rapidly during favorable conditions and then die off suddenly. Snails fill the ecological niche of detritivores, promoting mineralization of debris from algal growth. Habitats are of small size and characteristically of 2 more or less distinct types: 1) reservoirs with snail populations active continuously or through much of the year at low densities and 2) dynamic biotopes, with residual aestivating snail populations that experience brief seasons of activity, with a series of population booms and massive die-offs until environmental conditions again force survivors into aestivation.⁴ These are recurrent themes in the literature on ecology of snail intermediate hosts of trematodes.^{5,6}

Olsen reported finding the snail intermediate host of F. hepatica on the Gulf Coast prairie of southern Texas in 2 general types of habitat. The first, semipermanent ponds (reservoir habitats, holding water year round or at least well into the summer) included barrow pits and sloughs, supporting snails in narrow bands between the banks and deep water. The second, temporary pools (dynamic biotopes, holding water only when precipitation exceeded evaporation so that there was some excess standing water), included marshy areas, shallow drainage courses, wagon tracks, cowpaths and

hoofprints. The temporary pools were the principal habitats, supporting snails along extensive soil-water interfaces when conditions were favorable. Drainages from leaking water troughs or wells provided both the permanence of the semipermanent ponds and the favorable conditions of the temporary pools.

Two generations of snails were produced each year, in winter and late spring, with most snails reproducing and dying at age 6 months. The juveniles of spring aestivated through the summer drought, emerged after the autumn rains began, and produced the winter generation. Infection of snails by F. hepatica was found at rates of up to 6.6%, but averaged 0.0051% for 16,276 snails examined.⁷ Malone, et al confirmed these findings in Louisiana, describing a major spring and a minor autumn transmission of liver flukes. Seasonal transmission patterns vary in other climate zones. For example, in the British Isles a major late summer and minor early summer transmission occurs.⁸

Mathematical models of fascioliasis and other snail-borne diseases - In his 1883 report on the life cycle of Fasciola hepatica, Thomas recognized the controlling effects of climate on life cycle progression. Unable because of drought to find specimens of the snail during the summer of 1881, it was not until flooding in 1882 that he could confirm his hypothesis that Lymnaea truncatula served as intermediate host.⁹ Ollerenshaw incorporated effects of moisture and temperature on development of the disease in Wales into an empirical model and used it to forecast severity of disease with the goal of warning farmers of impending epizootics.¹⁰ He stated

that snail habitats will develop only 1) where topography, soil type and drainage systems permit the soil to attain field capacity with a slight free surface of water during the season of snail activity and 2) when rainfall and evaporation permit.¹¹ His model was extended, with modifications, to other areas.¹² Greater understanding of the ecology of snail and fluke and the advent of the computer revolution made possible the development of more data-intensive climate-based models. In Louisiana, where Ollerenshaw's model did not adequately account for temperature stress¹³, Malone, et al devised an empirical model based on the Thornthwaite water budget and the growing degree-day concept.¹ Recently, Goodall, et al reported development of an empirically fit, climate-based system that correlated closely with the rate of slaughterhouse liver condemnation data in Northern Ireland¹⁴.

Working on schistosomiasis, the major snail-borne disease of man, Hairston used ecological life table analysis to show gaps in knowledge that needed to be filled in order to develop a deterministic predictive model for the epidemiology of schistosomiasis. Compensatory mechanisms allow the parasites to achieve equilibrium population in a range of transmission rates, failing only at transmission rates so critically low that the probability of single-sex infections accelerates. He proposed that measures for control (in lieu of eradication) of schistosomes and their snail intermediate hosts might be successful if transmission could be kept below those critical rates, although breaks in control could lead to disastrous outbreaks of disease.¹⁵ However, since

both F. hepatica and F. bulimoides are parthenogenetic and have tremendous reproductive potential, any transmission rate greater than zero could perpetuate the disease, suggesting that nothing short of eradication would suffice, as pointed out by Boray writing on L. tomentosa.¹⁶ Fortunately, severe disease is rare in cattle so that, for this host-parasite system, limits on transmission might be considered an adequate economic goal.

Crofton published a seminal and more general deterministic mathematical model of host-parasite population relationships based on 1) degree of overdispersion of parasites in hosts; 2) parasite reproductive success (A) and transmission rate (F) (combined into an achievement factor, A_f); and 3) pathogenicity of the parasite. The overdispersion and pathogenicity effects were considered intrinsic for a given host-parasite system. His model suggested that increases in A_f , within limits observed in host-parasite populations, would lead to markedly lower equilibrium host and parasite population levels. The transmission rate, a function of host population size, would, in an agricultural setting, increase as stocking density increases. Favorable climatic conditions and increased habitat extent would both increase A_f through its term for parasite reproduction.¹⁷ May refined Crofton's model by limiting the effect of host population size on the transmission factor and also linking host and parasite population sizes in estimating the transmission factor, enhancing the tendency of the model to reflect observed stability in equilibrium population levels.¹⁸

Smith generated mathematical models of fascioliasis reflecting density-dependent constraints on populations of F. hepatica, with 1) reductions in fluke fecundity as burden increased in sheep and 2) limits on metacercarial production from snails with multiple infections.¹⁹ Wilson and Taylor exposed various density levels of snails (in a range with 25-fold variation) to miracidia at densities 1 to 4 times those of the snails, generating a curvilinear response surface²⁰ which suggested that 100% parasitism is unlikely in nature. Interpreting this work, Boray stated that infection rates of snails exposed to high miracidial density were lower than expected after accounting for multiple miracidial infection of snails, and that this indicated that individual susceptibility of snails was also an important factor in limiting snail infection rates.²¹ Boray described high infection rates and metacercarial production in small snail populations in the field. He presented laboratory data suggesting that at 5 densities of 0.3 to 13 snails/dm², snail infection rates and metacercarial shedding balanced snail densities to produce very limited increases in metacercarial production with increased population density. Unfortunately, he did not describe the methods used to achieve these results, so that interpretation is equivocal. In a second experiment, he showed that at higher population densities the snails were smaller, associating reduced growth rate with reduced parasite burdens. A third experiment associated increased size, number and cercarial content of redia in snails with better nutrient conditions.¹⁶ This agrees with earlier landmark work by Kendall.²²

Taken together, these results suggest that habitat-related risk is less dependent on snail population density than might be expected. Instead, they suggest that metacercarial production per habitat, the "bottom line" of snail-related habitat risk, is determined by habitat area and availability of nutrients. This study focuses on the component of individual farm risk of fascioliasis related to areal extent of snail habitat, and a method for estimating extent.

Rosenfield, et al, working on schistosomiasis in Iran, developed and verified a simple, effective model predicting change in prevalence (rather than equilibrium population levels) of schistosomiasis, based on only 2 variables: 1) linear extent of accessible snail habitat along existing or planned irrigation waterways (corresponding to likelihood of contact) and 2) initial size of the infected human population (corresponding to miracidial shedding rates). The model fit well with actual data for 54 villages over 12 years of irrigation development. This model was modified to account for different kinds of control measures (chemotherapy, molluscicide and habitat destruction), and was used to compare cost and effectiveness of these measures, singly and in combinations. It suggested additional modifications incorporating frequency of human contact with water (accounting for both exposure and infection terms) and climatic effects.²³ This model is relevant to the current studies because it incorporates a quantitative estimator of habitat risk based on an estimate of habitat extent.

Meek and Morris developed a systems analysis simulation of ovine fascioliasis, including a variety of parameters but concluding

that financial return depended upon stocking rate and the proportion of the farm occupied by snail habitat.²⁴ However, unlike the model of Rosenfield et al²³, their model provided no way of incorporating an estimate of snail habitat extent for unsurveyed ground.

Others have alluded to or implied importance of habitat area in determining danger to grazing stock. Ollerenshaw stated that one effect of ideal moisture conditions during the season of snail activity was to increase the area colonized, which both increased danger to stock directly and enhanced growth (and parasite transmission) potential for individual snails.¹¹ He maintained that the dominant factor in severity of fascioliasis is the duration of wetness of soil in flukey areas during the months of snail activity.²⁵ Malone suggested that the variation in severity of fluke risk between individual farms in a given climate region was as great as the variation in risk for the region between climate years. He stated that once the effect of regional climate risk is accounted for, the weak link in design of control measures is assessment of the role of individual farm risk.²

Wright and Swire examined the distribution of Lymnaea truncatula with respect to soil type in South Wales, concluding that snail habitat clustered on gleyed soils (which are wet on the surface much of the year), and that permanent snail habitat and fluke transmission sites were restricted to the wetter areas within these soil types. Again, potential for temporary extension of habitat during wet summers was noted. They suggested use of soil maps for qualitative assessment of areas of general fluke risk, for

identification of particular fields at risk and for guidance in location and sampling of snail habitats.²⁶ However, they developed no means for quantitative assessment of habitat risk for individual unsurveyed farms.

Geographic information systems - Modern geographic information systems technology provides a potentially powerful new way to evaluate spatial relationships in epidemiology. A geographic information system (GIS) has been defined as a decision support system involving the integration of spatially referenced data in a problem-solving environment.²⁷ It uses computer mapping technology to attach a data base to cartographic representations of geographic features (points, lines or polygons). A thematic map (representing one type of feature) forms one overlay (level of mapped data) in the computer. Data can originate from maps and ground surveys as in the current studies, or from aerial photographs or remote sensing devices aboard aircraft or satellites. An important capability of GIS is performance of operations on single or multiple overlays to generate new overlays conveying novel information. The current studies describe the relationship of snail intermediate host habitat to environmental factors reflected in soil maps. Soil and habitat overlays are compared to generate an overlay of novel information, a model of distribution of snail intermediate host habitat as a hypothesis for testing.

In a broad sense, any mappable feature can be entered into a GIS, and evaluated for possible insight into the epidemiology of a disease. In the USSR, Pavlovsky developed a doctrine of natural

nidality of a series of diseases transmitted among animals in the wild wholly or partly by vectors (but mainly by hemophagous insects and ticks). These diseases were associated with definite geographic landscapes or certain landscape features and transmission was seasonal; they were usually transmitted through attack by arthropods or other animal vectors to humans who penetrated the nidi during the season of transmission. Diseases with natural nidality included tick spirochetoses and rickettsioses, a number of encephalitides, plague and tularemia, and rabies. Nidal helminthic diseases included opisthorchiosis, diphyllbothriosis, trichinellosis, and bilharziosis. A number of these diseases occurred in landscapes of varied character, but were closely associated with biotopes of characteristic elevation, aspect, proximity to rivers, etc..²⁸ These mappable features could be included in a GIS along with maps of cultural features to facilitate epidemiologic work on these diseases.

Application of GIS to the epidemiology of disease is in its infancy. In an early computer mapping application, population densities of female Culex quinquefasciatus in the storm sewers of Houston, TX were surveyed over a year's time. Contour maps were generated demonstrating clustering in older residential areas, regardless of socioeconomic status, but apparently related to soil subsidence, which caused misalignments in sewer pipes leading to standing water.²⁹

In a study of theileriosis in Africa, a data base was assembled from available literature, maps of a climate stress model related to the tick vector, Rhipicephalus appendiculatus, and remotely sensed

data. The climate stress model was compared to reported distribution of ticks and found to be of high specificity but low sensitivity. They indicate that suitable climatic conditions existed where ticks had been reported (in southeast Africa). However, it also indicated as suitable large areas of south, central and west Africa and a smaller area of north Africa where ticks had not been reported. The authors speculated that some areas of suitable climate held no ticks because of inadequate sampling; that some were covered by vegetation unsuitable to the tick; and that perhaps some areas constituted suitable habitat protected only by geographic barriers, and were at risk for importation of the disease. They suggest that incorporation of other overlays, particularly a vegetation index derived from satellite remotely sensed data, to improve the sensitivity of their system.³⁰

Remotely sensed data, a source of broad scale environmental data amenable to incorporation in GIS models, has been used in a few field studies of vectors of disease (including studies of habitat of the mosquitoes Aedes sollicitans, Psorophora columbiae, and Anopheles freeborni; the tick Amblyomma variegatum; and tse-tse flies, Glossina spp.), as reviewed by Hugh-Jones. Only a few of these studies involved a functional GIS that incorporated mappable data not gathered by remote sensing or aerial photography.³¹

Cross and Bailey developed a discriminant analysis model based on weather data for schistosomiasis in the Caribbean and Phillipines which fit known disease status in the area of weather stations with 87.1% and 93.2% accuracy, respectively.³² Cross, et al then used classified satellite data to resolve misclassifications where

landforms modified results and to remove urban areas from consideration. An interpolation scheme was applied to estimate weather variables at sites remote from weather stations, producing a probabilistic disease distribution map.³³ Hugh-Jones combined pre-existing maps of vegetation and mosquito larval habitat on Guadeloupe³⁴ with Landsat image classification in a GIS to identify previously unknown areas of habitat.³¹

Evaluation of herd infection rates - Any successful GIS for assessing habitat extent of snail vectors might be used to locate high risk zones that can be subjected to snail control or avoided by management. Ultimately, it might be used for its broader epidemiologic predictive value on the effect of snail habitat extent on infection intensity and prevalence of the disease agent in the final host. The latter application is dependent on accurate means of evaluating fluke burdens in final host populations. For fascioliasis in cattle, prevalence can be evaluated on a herd basis by fecal egg shedding rates³; however, the method is not highly accurate, and better methods, such as reliable serologic tests, are needed.^{35,36,37} Examination of sentinel calves or herd cohorts at necropsy and other more involved epidemiological methods are expensive and time intensive, and are not practical for broad scale evaluations.

The number of eggs of F. hepatica shed by cattle varies over a year in a pattern controlled by timing and severity of infections and age of the cattle. Following experimental infection there is a

pre-patent period of 8-10 weeks, rising egg passage peaking at 18-20 weeks, and an asymptotic drop to or near 0 by 30-40 weeks.^{38,39,40} Higher infection intensity may shorten the period of egg shedding.⁴¹ Prevalence rises with age to 4 years, then stabilizes, rising again in aged cattle; intensity of egg passage rises to a maximum at 3-4 years, then declines, stabilizing in aged cattle.⁴² It appears that there is a partial resistance, reaching a maximum after the fourth year of age, and that this is reflected in lower egg shedding rates and smaller fluke burdens. Although most flukes are eliminated one year after infection, most animals are susceptible to reinfection in subsequent transmission seasons.⁴³

A diurnal rhythm in egg shedding has been reported in cattle, with low intensity in the morning and substantial (3- to 4-fold or more) increases during the day from some individuals, peaking at about 1:30 p.m. and falling off again by evening; however, other individuals displayed only slight diurnal variation in egg shedding.⁴⁴ Nighttime and early morning samples were not evaluated.

The rumen fluke Paramphistomum microbothrioides coexists with F. hepatica in cattle of the chenier plain and in the intermediate host, F. bulimoides. The minimum length of the life cycle is perhaps 6 months, one month longer than for F. hepatica, but this varies with temperature in both species. Adults of P. microbothrioides are difficult to distinguish from P. microbothrium, which has a world-wide distribution, and may be only a strain

variant. The eggs of P. microbothrioides are similar to those of F. hepatica, and must be distinguished in examination of fecal sedimentation preparations. Paramphistomes are considered innocuous in temperate areas.^{45,46,47} Egg shedding for P. microbothrioides is little affected by the flukeicide available in the United States at the time of this study^{48,49}, suggesting that egg counts for rumen flukes might be used as a surrogate for F. hepatica egg counts, and fascioliasis risk, in recently treated herds.

The following 3 articles report results of investigations designed 1) to construct a GIS-based model for estimating snail habitat extent on a large primary study site, 2) to test this model after extrapolation to additional farms within the same ecological zone and 3) to determine whether habitat extent could be related to herd infection prevalence or intensity in the cattle herds studied.

Manuscript I. FASCIOLIASIS IN CATTLE IN LOUISIANA: USE OF A SOIL
MAP IN A GEOGRAPHIC INFORMATION SYSTEM TO MODEL HABITAT OF THE SNAIL
INTERMEDIATE HOST, Fossaria bulimoides

Stanley H. Zukowski, D.V.M.; John M. Hill, Ph.D.; John B. Malone,
D.V.M., Ph.D.

Keywords: Fasciola hepatica; fascioliasis; cattle; Fossaria
bulimoides; habitat; soil map; model; geographic information system;
risk assessment.

SUMMARY

A geographic information system (GIS) was used to assemble and analyze data on the spatial distribution of habitat of the snail, Fossaria bulimoides, an intermediate host of Fasciola hepatica. A model of habitat was developed on a representative 760ha farm on the Chenier Plain of southwestern Louisiana. Input maps were: 1) soil series (type), 2) fencelines, 3) F. bulimoides habitat, and 4) soil salinity. Habitat occupied 3.5% of the farm. Distributions of habitat and soil series were compared. Habitat was strongly associated with interfaces of marsh and chenier (relict beach) soils, more consistently along a chenier waveface than on the backslope.

The model simulated snail habitat along soil series interfaces, and was refined to correct for effects of salinity. The goal was to develop a tool for estimating individual farm risk of fascioliasis, to augment a regional climate-based forecast of annual transmission. Simulated habitat occupied 11.1% of farm area, and covered 76.7% of actual (surveyed) habitat. Being based on a soil map, the model accurately located most natural F. bulimoides habitat. However, habitat created by man (i.e., drainage ditches) or located in unmapped soil anomalies was not modeled accurately.

The model developed on the primary study farm was extrapolated to a 29,000ha extended study area of the Chenier Plain region. Simulated habitat covered 12% of the larger area. The extrapolation forms a hypothesis suitable for testing and refinement by examination of other farms in the area, for ultimate application to the entire 1295km² Chenier Plain ecosystem of southwest Louisiana.

Fossaria (Lymnaea) bulimoides is an amphibious lymnaeid snail bearing a strong resemblance in ecological characteristics to Lymnaea truncatula in Europe.^{7,11} Both snail species depend on seasonal, temporary wet zones in poorly drained soils. In the 1940's, Olsen described the snail bionomics, seasonal transmission and treatment of bovine fascioliasis on the Texas Gulf Coast.⁷ More recently, Malone, et al extended these findings in Louisiana^{50,51}, and used the Thornthwaite water budget to develop a climate-based forecasting system^{13,1} that is now used to generate seasonal recommendations on the economic advisability of anthelmintic treatment against F. hepatica in Louisiana.⁵² Climate forecasts only have regional value, however, and do not account for the great variation in the severity of fascioliasis found between farms, or even between pastures on a given farm.^{3,2}

The object of the current study was to develop a spatial model for estimating variation in the extent of snail host habitat that could be used, in conjunction with regional climate forecasts, to assess the severity of fascioliasis risk in individual cattle operations. The study area, the Chenier Plain of southwestern Louisiana, is a 1295km² ecosystem containing broad expanses of coastal marsh nested behind a series of landlocked beaches (cheniers). The cheniers are a series of narrow, linear ridges subparallel to the coastline. There are striking contrasts in soils, with the loose sands of the relict beaches juxtaposed to the heavy, gleyed clays of the surrounding marsh.⁵³ Cattle range over much of the area, and fascioliasis is endemic. Prior F. hepatica

epidemiologic studies in the Chenier Plain region, using aerial photography, vegetation surveys and soil maps, suggested 1) that F. bulimoides habitat clusters along interfaces of cheniers and marsh; 2) that variation in fluke risk between grazing units depends on the extent of habitat on pastures^{3,51}; and 3) that a model based on soil maps may be useful to indicate habitat location and extent.²

Previous studies showed that high salinity due to proximity to the Gulf of Mexico excludes habitat from most of the area between Front Ridge and the current beach, and revealed a transition from pasture grasses to more saline-tolerant plant communities that indicated the approximate limits of F. bulimoides with respect to salinity.⁵¹ The current report describes development of a geographic information system (GIS) model designed to discriminate between high and low risk of fascioliasis in individual cattle grazing units, based on the hypothesis that snail habitat clusters along soil interfaces reflecting chenier-marsh interfaces.

A Geographic Information System is a computer-based system in which mapped entities (points, lines, or polygons) are input and processed both in terms of geographic location and in terms of identifying or descriptive information attached to them as computer codes. Users can enter a series of maps as overlays, or layers of cartographic data. Each overlay contains the data for a single characteristic or factor (i.e., soils, land use). Arithmetic or Boolean analysis of multiple overlays can be used to generate new overlays.⁵⁴

Materials and Methods

GIS - The GIS consisted of ELAS (Earth Resources Laboratory Applications Software)⁵⁵, developed by NASA for processing spatial data, operated on a minicomputer^a at the Remote Sensing and Image Processing Laboratory. The ELAS software consists of a central control root program serving a variety of modules designed to perform various functions. Modules used in this study are shown in Table 1, with brief descriptions of their uses.

Soil series map - Advance copies of soil maps covering the Cameron-Creole Watershed, provided to the Remote Sensing and Image Processing Laboratory for use in another project^{b,56}, were used. The survey party of the United States Soil Conservation Service drew them onto translucent polyester overlays on USGS orthophotomaps, so that they were registered to the Lambert conformal conic projection. The taxonomic classifications of soils on the farm appear in Table 2.

Study area - The model was developed on the primary study farm. This was a 760 hectare site on the Chenier Plain, within the Cameron-Creole Watershed and adjacent to the Gulf of Mexico. An additional 29,000 ha area within the watershed was selected for further study. The farm and additional study area (Plate 1) appear on the following U.S. Geological Survey 7.5' Series orthophotomaps or topographic maps: Grand Bayou, Cameron, Creole and Grand Chenier. The farm boundaries are irregular, encompassed by a

rectangle with its northwest corner at approximate latitude and longitude 29-47'20"N, 93-15'15"W and its southeast corner at 29-46'N, 93-12'W. Plate 1a shows a soil map. Other features are shown in Fig 1. The farm is divided into 3 grazing units, identified as north, east and west. Natural features of the farm include a major chenier (Front Ridge), its waveface and backslope, some minor ridges, and marsh. This farm had been previously studied to define the seasonal epidemiology of fascioliasis and formulate strategic control programs², and it was here that clustering of F. bulimoides habitat about marsh-chenier interfaces was first described.⁵¹

The extended study area (Plate 1c) has irregular boundaries, encompassed by a rectangle with its northwest corner at approximate latitude and longitude 29-52'N, 93-20'30"W, and its southeast corner at 29-45'30"N, 92-59'50"W (Plate 1c).

Aerial photography - Aerial photography of the primary study farm was obtained by commercial contract^c on March 18, 1983 by use of an aerial camera (15cm focal length, negative size 23 X 23cm)^d from an altitude of 460m (+/- 5%). Flight lines were maintained on autopilot, with the camera rotated to compensate for crabbing due to crosswind, giving a view parallel with the flight path. Camera level was controlled by use of a bubble level. High quality panchromatic film^e was used, and prints were obtained on a stable, resin-coated paper^f. This coverage was originally obtained at a relatively large nominal scale of 1:3000 appropriate⁵⁷ for a study

of the relationship between the distributions of snail habitat distribution during the season of activity and range vegetation⁵¹.

Habitat Survey - Researchers surveyed the farm for F. bulimoides between February 3 and March 4, 1986 to map snail habitat. Transparent overlays were taped onto the aerial photographs. Investigators traversed the farm afoot, guided by interpretation of the aerial photography and by prior knowledge of the site from 3 prior years of habitat surveys.⁵¹ Boundaries of snail habitats were re-located and traced onto transparent acetate overlays taped to the aerial photographs. Emphasis was placed on interfaces on the aerial photographs between intermediate to dark gray tones (signifying low ground or depressions with moisture adequate to support the snail), and lighter tones (signifying higher or better-drained, drier soil). A few foci of habitat discovered in previous years held no snails at the time of this survey, and a few foci of habitat were found on ground where snails had not occurred in previous years. These differences were interpreted as reflecting expected variability in utilization of marginally suitable habitats.⁴ Where surveyors found habitat, they established the margins by searches along a series of short transects perpendicular to the trend of the landscape. Sites of habitat found in previous years⁵¹ were sketched as well. Where not easily located by photointerpretation, farm boundaries and fencelines dividing pastures were also sketched onto the aerial photographs.

Map of Salinity Effect on Habitat - A map of the dichotomous variable, suitability of salinity for F. bulimoides habitat, was generated by photointerpretation of vegetation cover and entered as a separate overlay in the GIS. Saline-tolerant marsh vegetation (on low, wet ground, frequently with conspicuous hummocks) was characterized by a dark background and coarse texture. Less salt-tolerant pasture grasses (on higher, drier ground adjacent to the chenier) were distinguished by finer textures and lighter tones.

Base map - The portions of the 2 USGS orthophotomaps (scale = 1:24,000) covering the primary study farm were cut out, aligned to match edges and taped together. They were enlarged to a scale of 1:6,000 and printed on polyester film by use of a commercial process camera to form the base map used in mapping surveyed features. The base map used the Lambert conformal conic projection of the orthophotomaps, and that projection was standard for this study.

Registration of maps - The high quality aerial photography approximated a plan view of features on level terrain, slightly distorted as described below. Scale varied slightly within individual aerial photographs due to minor variations in aircraft/camera attitude (pitch, roll or yaw). Scale varied between photographs because of limited variation in altitude along a flight line. Topography introduced limited distortion⁵⁸, as there was little relief in the area.⁵³ Mapping requires registration, or

removal of these distortions, and introduction of corrections to approximate a standard projection of the surveyed features.⁵⁹

The surveyed features (habitat boundaries, farm boundaries and fencelines, and salinity zones) overlain on the aerial photographs were registered by use of a Zoom Transfer Scope.⁹ This is an optical device for map registration, having a single ocular receiving light from two objectives. It was used with one objective focused on a base map and the other on an aerial photograph. In the ocular one saw a dual image control points (clearly defined features common to map and photograph). Accessory lenses allowed rotation, translation, scaling, and limited distortion (stretching along one axis of variable orientation) of the image from the photograph. By these manipulations, the images of 3 control points from the photograph were registered to, or superimposed on, their counterparts from the image of the base map, forming a single triangle. Then other features within the triangle on overlays of the photography were also in registration.⁶⁰ The outlines of each type of feature were traced onto separate transparent acetate overlays of the base map, to produce separate maps of habitat, fencelines and salinity.

The transparent overlays were oriented to the base map by pin registry. Pin registry consists of a series of holes punched at regular intervals along one edge of the base map and its overlays. A metal bar bears pins that fit snugly into the holes. The base map and one or more transparent acetate overlays were fitted onto the

bar. Pin registry allowed overlays to be removed and replaced into the correct frame of reference consistently and precisely.

Digitization - The registered features on base map overlays were digitized for entry into the computer. The base map and an overlay were fixed to a digitizing table, underlain by a 2-dimensional grid of electronic sensors.^h The sensors detected the location of a signal from a hand-held cursor and transmitted the x,y coordinates of the point to a computer file. The features on the overlay (soil series, pasture identification, presence or absence of snails, or salinity regime) were entered into a single file, or overlay, of the GIS. ELAS module DGTZ generated lines and polygons (closed figures) from point data.

Rasterization - The computerized maps of soils, habitat, and farm and pasture boundaries were rasterized (divided into an x,y grid of square picture elements, or pixels, each representing 10m on a side) by use of the ELAS module PGUD. In effect, the grid was superimposed on the polygons created by digitization, defining the limits of spatial resolution for the study. All pixels in contact with polygons of a given code were then assigned that code. There is a one-for-one correspondence in x,y coordinates between pixels from the different maps. Analyses and other operations were then done on a pixel-by-pixel basis.

Determination of soil interfaces to be fit by the model - Soil interfaces to be included in the model were selected by examination of the superimposed soil and habitat maps. Soil interfaces along which snail habitat appeared to cluster were incorporated into the model.

Generation of the model - The NEGH (Neighborhood) program was used to generate the model. It detects interfaces between pixels of specified codes and assigns a new code to pixels adjacent to that interface, in specified octant directions (i.e., north, northeast, east,...) from the interface.⁶¹ NEGH was used to fit a model of distribution of F. bulimoides habitats by generating zones from the soil interfaces selected above, in increments of one pixel-width (10m). The program widened a soil interface first to one side, then to the other; at each step the incipient model was compared with the map of actual habitat. A decision was made empirically on a diminishing-returns basis as to whether the last increment covered enough pixels of actual habitat while incorporating few enough pixels of non-habitat to justify incorporation into the model. If so, another increment was generated; if not, generation of model habitat along that side if the interface ceased. When completed, the model classified each pixel on the farm into 3 zones, as follow: 1) habitat (on waveface); 2) habitat (on backslope); or 3) non-habitat.

Correction of the model for salinity - The model generated habitat zones in the saline area between Front Ridge and the current

beach. Where the vegetation-based salinity map indicated that salinity exceeded the tolerance of F. bulimoides, the model was amended by re-conversion of pixels to the code of the original soil map.

Evaluation of the fit of the model - The resultant model was compared back to actual habitat. The following descriptive statistics were compiled for each of the 3 model zones, over the primary study farm and within each subunit: 1) the number of pixels occupied by the zone; 2) % of total area occupied by the zone; 3) % of total actual habitat (determined by ground survey) falling within the model zone; 4) % of model habitat comprised of the zone; and 5) classification accuracy (% of pixels in the zone that were correctly classified with respect to presence or absence of habitat).

Results.

Comparison of Habitat and Soil on the Primary Study Farm.-

Table 3 and Plate 1a summarize a comparison of habitat and soil series. Habitat occupied 3.5% of the farm, but clustered on soils of the Creole series (39.3% of farm area, 65.9% of the habitat) and Peveto series (5.4% of the farm, 6.8% of habitat). Habitat along chenier-marsh interfaces is described below (Plate 1a and Fig 1; letters A through H in the following discussion refer to points identified on Fig 1.)

Snail habitat clustered most consistently along the waveface of Front Ridge; here, marsh soil of the Creole series abuts soils of

(from east to west) the Peveto and Hackberry series (A). However, habitat did not extend farther westward to cover the the waveface interface of Hackberry-Mermentau complex and Creole series soils.

Habitat clustered less consistently along the backslopes. On the backslope of Front Ridge, it lay along the interface of Creole series with transitional chenier soil of the Mermentau series (B). It also lay along the backslope of a minor ridge situated between Front Ridge and the current beach. Here, habitat lay along an interface between soils of the Hackberry-Mermentau complex and the Creole series (C).

In addition to the major clusters of habitat at interfaces of Creole series marsh soils with chenier soils, minor foci occurred elsewhere. On the backslope of Front ridge above the chenier-marsh interface, the interface of the Mermentau series and Hackberry-Mermentau complex held several small foci (D, D', D''). The largest of these foci (E) extended northward from a ditch found to drain a pasture near the top of the chenier, to the edge of a slough. Also, several small foci (F) adjoined the slough, which drained along a strip of Mermentau series soil here. From ground level, the center of the slough held a heavy, gleyed clay similar to that of the Creole series.

Yet farther up on Front Ridge, foci of snail habitat occurred at an interface of Hackberry series and Hackberry-Mermentau complex (G), and within the main unit of soil of the Hackberry-mermentau complex (H). On ground investigation, these habitats were found in moist depressions on Front Ridge, discernable on the aerial photographs as foci of dark tones, approximately 3 to 12m by 15-30m.

No foci of F. bulimoides habitat were found associated with the Felicity (current beach) or Scat lake (deep marsh) soils.

The three pastures differed in habitat extent, as depicted in Fig 2. Habitat extent was 5.4% in the west pasture, 2.4% in the east pasture, and 3.6% in the north pasture.

Selection of soil interfaces for modeling - The comparison of habitat and soil maps substantiated the hypothesis that habitat clustered along soil series interfaces (Plate 1a, Fig 1). Interfaces of the Creole series with chenier soils indicated sites of the major natural habitat clusters, with the waveface of primary and the backslope of secondary importance. The chenier-marsh interfaces of the Creole (marsh) series with the Peveto and Hackberry series (waveface of Front Ridge), the Mermentau series (backslope of Front Ridge), and the Hackberry-Mermentau complex (backslope of minor ridge) were selected as the basis for development of a computer-generated spatial model of F. bulimoides habitat.

Generation of habitat model on the primary study farm - Model habitat was generated along the selected soil interfaces. The model classified the farm into 3 zones: waveface habitat, backslope habitat, and nonhabitat. Table 4 gives the widths of zones of simulated habitat generated from the waveface and backslope interfaces.

Correction for salinity - Initially, much simulated habitat lay along soil interfaces between Front Ridge and the current beach, in the saline area shown unsuitable for survival of the snail. The model habitat here lay primarily on backslopes, along both the current beach and the minor ridge between the current beach and Front Ridge. Interfaces between the Creole series and both the Mermentau series and the Hackberry-Mermentau complex (Plate 1a) were involved.

Evaluation of fit - A map of the final model for the primary study farm appears in Plate 1b, with a comparison to actual F. bulimoides habitat, and is summarized in Table 5 and Fig 2.

Along the waveface, simulated habitat occupied 3573 pixels (5.2% of the farm), of which 1225 held actual (survey confirmed) habitat (50.6% of actual habitat found on the farm). Along the backslope, simulated habitat occupied 4078 pixels (5.9% of the farm), of which 633 held actual habitat (26.1% of actual habitat). Combining waveface and backslope, simulated habitat occupied 7651 pixels (11.1% of the farm), of which 1858 held actual habitat (76.7% of actual habitat). The model detected the 3.5% of total farm area comprised of actual habitat with a nominal sensitivity of 76.7% (Table 5).

Simulated non-habitat occupied 88.9% of the farm, and included the 23.3% of actual habitat missed by the model. Major foci of missed habitat are identified on Plate 1b. On the waveface, part of a particularly broad section of habitat on the main waveface near the east end of the farm was missed (a). On the backslope, near the

east end of the farm, missed foci include those previously identified as lying on a natural slough and being affected by artificial drainage (b). Finally, a number of small foci of actual habitat up on the chenier, not associated with a marsh interface, were missed (c). Classification accuracy for non-habitat was 99.1% (60768 pixels of non-habitat in 61333 total pixels); nominal sensitivity of the model was 76.7%.

The accuracy of the model varied markedly between pastures (Fig 2). Actual habitat occupied 4.7% of the west pasture. Simulated waveface habitat occupied 5.0% of the pasture; actual habitat in this zone occupied 1.8% of the pasture (classification accuracy $1.8/5.0 = 36.0\%$, a 7-fold improvement over the 4.7% accuracy expected for a random "flip of the coin" for each pixel in this pasture). Simulated backslope habitat occupied 13.4% of the pasture, with 2.9% actual habitat (classification accuracy = 21.6%). Simulated non-habitat covered remaining 81.6% of the pasture; however, actual habitat was found on 0.7% of this zone, giving a classification accuracy of 99.1% (slightly better than the 95.3% accuracy expected for a random "flip of the coin").

For the east pasture, the simulated waveface habitat occupied 4.3% of the area. Actual habitat occupied 1.8% of this zone (classification accuracy = 41.9%). The northern fenceline of this pasture lies just above the waveface of Front Ridge, almost entirely excluding zones of non-saline backslope interface (a small area of simulated backslope habitat, 15 of 20,930 pixels, was generated here, of which none held actual habitat). Simulated non-habitat

covered 95.6% of the east pasture; however, actual habitat occupied 0.6% of this zone (classification accuracy = 99.4%).

On the north pasture, simulated waveface habitat occupied 5.4% of the area, but actual habitat occupied only 0.1% of this zone (classification accuracy = 1.9%). Simulated backslope habitat occupied 15.9% of the pasture, but only 0.5% of this zone was actual habitat (classification accuracy = 3.1%). Simulated non-habitat covered 78.8% of this pasture; however, 3.0% of this zone held actual habitat (classification accuracy = 96.2%).

Model Extrapolation - Based on findings at the primary study farm, computer generation of simulated habitat along chenier-marsh soil series interfaces was repeated over the extended study area. This yielded an extrapolation of the model (Plate 1c). There was no available large-scale aerial photographic coverage of this area to extrapolate salinity findings from the initial farm. Consequently, the model extrapolation was not refined by a correction for salinity effects. The model suggests that 12% of the extended study area is interface suitable for F. bulimoides habitat.

Discussion.

The GIS model developed in this study generated simulated habitat zones covering 11.1% of the farm along selected soil interfaces, in which zones were found 76.7% of field survey-verified habitat. The model classified the farm into 3 zones: waveface habitat, backslope habitat and nonhabitat. Habitat was scattered,

even within the simulated habitat zones; 24.3% (1858/7651) of the pixels within zones of simulated habit actually held snails. Snails occupied interfaces on wavefaces more consistently than on backslopes, presumably reflecting the more consistent morphology of waveface interfaces. Results of the simulation suggest that the model may be sufficiently accurate to broadly categorize farms in terms of snail habitat-related fascioliasis risk (e.g., low, moderate, high and severe risk).

Limitations of the model were primarily related to the generalized nature of information available in soil maps. The 23.3% habitat missed was mainly found in minor unmapped soil extensions or anomalies, or resulted from activities of man. In the north pasture unit, habitat was found along a slough for which the soil map showed no interface with the creole soil series (Plate 1b, b). The slough connected 2 units of Creole soil and may represent a strip of Creole soil too narrow to be mapped according to standard SCS soil survey procedures. A man-made drainage ditch ran down from the chenier into the slough, providing a gentle flow of water suitable for F. bulimoides. Additional small foci of habitat lay in small depressions on chenier soils (Plate 1b, c). The model missed the southernmost extent of a particularly broad area of waveface habitat (Plate 1b, a). When the 3 pasture grazing units on the study farm were considered, classification accuracies achieved for the east and west pastures were similar to those reported for the entire farm. However, results for the north pasture were markedly poorer; the model missed most of the actual habitat (Plate 1b, b). Much of that habitat lay along the slough (Fig 1 D'', E, F).

A suggested, but unverified, mechanism for the clustering of snail habitat along chenier-marsh interfaces is that rainwater may collect within the lens of pourous, sandy soils of a chenier, be retained by the underlying marsh clays, and seep out along the interfaces.¹ This would be consistent with the proclivity of Lymnaeid snails for seepages⁶, and with the more consistent occurrence of snail habitat along the more regular wavefaces than along backslope interfaces of cheniers.

Habitat extent has long been recognized as an important determinant of F. hepatica risk between farms in a given region. Using a mathematical systems analysis approach, Meek and Morris found climate and habitat extent, along with several other determinants, useful for predicting financial returns of control measures on an Australian sheep operation. Their model was based on a single farm; they offered no practical way to extend their findings to other farms on a broad geographic scale, or to localize foci of snail habitat except by exhaustive ground survey.²⁴ English workers attempted to relate snail habitat to a soil map and found that L. truncatula habitats were found almost exclusively in small, particularly wet foci on the more poorly drained soil series. Soils could not be used as the basis for localized predictions of foci of habitat, or to predict disease risk except in a general sense. There was no indication that habitat clustered along soil interfaces.²⁶ It is possible that the unusual ecological contrasts in the chenier plain region contributed to the apparent good fit of the model to the farm in this study.

Working on schistosomiasis, a snail-borne parasite of man, Rosenfield, et al developed an effective model for transmission based on linear extent of the water bodies that provide habitat in Iran for the intermediate host.²³ While it might have been simpler to base the model for the current study on linear extent of soil series interfaces, generation of zones reflecting the widths of actual habitats gives an areal component to the model. It permits addition of other areal data, such as the salinity map used in this study, to refine the model. Additional data might include aerial photographic interpretation to suggest the presence of habitat in soil anomalies. Digital remotely sensed imagery or infrared photography might reveal sites in sloughs and other depressions by detection of suitable soil moisture or characteristic vegetation communities (Fig 1, D - H).^{13,62,63,64} Such data might indicate soil salinity^{65,66}, to allow extrapolation to the study area of the limitations on habitat extent imposed by salinity. A limited amount of on-site survey, guided by examination of model output and additional data, may be necessary for complete evaluation of risk on some farms or units, but with far less effort than for a general farm survey. It is possible that this combined approach would detect most 'near miss' habitat encountered on the primary study farm (Plate 1b, a and b).

The modeling method described here may provide a practical approach to estimating the distribution of habitat of the intermediate host of F. hepatica and demonstrates some of the power and flexibility of the GIS as a tool for ecological investigations.

The model was developed on a primary study farm from commonly available data (soil maps and aerial photography) to provide a method for predicting individual farm risk of fascioliasis. The GIS allowed separate analyses for the farm and each of the 3 grazing units, including separate comparisons of simulated and actual (surveyed) habitat along wavefaces and backslopes in each unit. An additional layer of data on salinity was accommodated. Using the GIS methodology based on the model developed at the primary study farm, the simulation was extrapolated to predict habitat location and extent over a 29,000ha geographic area. Successful verification of the extrapolation will allow further extrapolation to the 1295km² chenier plain ecosystem of a system for assessment of farm or pasture risk, and will further the goal of integration of the GIS model with a regional climate forecasting method. In combination, the 2 techniques might form the basis for development of more cost-effective control programs, including more accurate annual decisions on the relative need for flukeicide treatment. In addition to providing an estimate of the relative fluke risk of individual farm units (by use of a land plot overlay), model output could be used to make management decisions, such as where to segregate younger, more susceptible stock; how to economically target molluscicide, should a safe and effective compound be developed; or how to effectively utilize habitat modification measures. Similar models might be developed for other diseases with strong environmental determinants.

TABLE 1 - ELAS modules used for this study and their functions.

<u>ACRONYM</u>	<u>Title - function</u>
FMGR	General purpose File Manager - to access other modules.
COMD	Common Image Display Module - to control display to the cathode ray terminal, which is interactive, in that it can accept input from a cursor.
PCAL	Calculator - to superimpose images from two or more overlays to produce a derivative image
PLYA	Polygon Acreage - to determine the frequency of occurrence on an image of pixels with each code and produce as tabular output the area and percentage of total area covered by pixels of each code
DGTZ	Digitizer - to accept and process input from the digitizing table.
PGUD	Polygon Update - to assign numeric codes from the polygon map created with DGTZ to the pixels of the raster grid.
NEGH	Neighborhood - to detect interfaces between pairs of pixels with specified different codes and change the code of the pixel on one side of the interface to a new value.

TABLE 2 - Taxonomic classifications of soils on the primary study farm.

<u>SOIL SERIES</u>	<u>TAXONOMIC CLASSIFICATION (TO FAMILY)</u>
CHENIER SOILS	
Peveto (Pe)	Mixed, thermic typic udipsamments
Hackberry (Hb) [*]	Sandy, mixed, thermic aeric haplaquepts
Mermentau (Me) [*]	Clayey over loamy, montmorillonitic, non-acid, thermic typic haplaquepts
MARSH SOILS	
Creole (Cr)	Fine, montmorillonitic, non-acid, thermic typic hydraquents
Scat Lake (Sc)	Fine, montmorillonitic, non-acid, thermic typic hydraquents

^{*}The Hackberry-Mermentau complex (HM) is recorded in areas where the Hackberry and Mermentau soil series intermingle or alternate in units too small to be mapped individually, in accordance with standard soil survey practice.

TABLE 3 - The soil series mapped on the primary study farm:
Percentage of farm and percentage of F. bulimoides habitat.

Soil Series	% of Farm	% of Habitat	Terrain Feature(s)
Creole (C) [*]	39.3	65.9	Marsh
Mermentau (M)	21.0	14.6	Transitional
Peveto (P)	5.4	6.8	Chenier
Hackberry (H)	3.4	1.5	Chenier
H-M Complex (X)	24.5	11.3	Chenier, minor ridge
Scat Lake (S)	5.0	0.0	Deep marsh
Felicity (F)	0.2	0.0	Current beach
Water (W)	1.3	0.0	Pond

F. bulimoides habitat as surveyed covered 3.5% of the farm.

^{*}Letters in parentheses relate to the classification of the map in Plate 1A.

TABLE 4 - Widths (m) to which model F. bulimoides habitat zones were generated from the respective soil interfaces on the initial farm.

INTERFACE	WIDTH	WIDTH	WIDTH
	UP	DOWN	TOTAL
	(onto chenier)	(into marsh)	
<hr/>			
Waveface			
Peveto-Creole	20	50	70
Hackberry-Creole	20	30	50
Backslope			
Mermentau-Creole	50	40	90
Hackberry-Mermentau			
Complex-Creole	N/A	40	40
<hr/>			

TABLE 5 - Sensitivity and specificity of the habitat model.

<u>MODEL HABITAT</u>	<u>ACTUAL HABITAT</u>		<u>TOTAL</u>
	<u>+</u>	<u>-</u>	
WF+	1225	2348	3573
BS+	633	3445	4078
MODEL +	1858	5793	7651
MODEL -	565	60769	61334
TOTAL	2423	66562	68985

NOMINAL SENSITIVITY ANALYSIS (ASSUMING
CORRECT CLASSIFICATION WITH RESPECT TO
ACTUAL HABITAT STATUS):

SENSITIVITY	0.767
FALSE + RATE	0.233
SPECIFICITY	0.913
FALSE - RATE	0.087

Plate 1A. Soil map of the initial study farm, showing habitat of F. bulimoides. Key to color coding: C - Creole; M - Mermentau; P - Peveto; H - Hackberry; X - Hackberry-Mermentau complex; S - Scat Lake; F - Felicity (beach); W - Open water; A - Habitat of F. bulimoides.

Plate 1B. Map of computer-generated model of spatial distribution of F. bulimoides habitat on the primary study farm, with actual habitat superimposed. Key to color coding: 1 - Waveface at chenier-marsh interface, snails present. 2 - Waveface at chenier-marsh interface, snails not present. 3 - Backslope at chenier-marsh interface, snails present. 4 - Backslope at chenier-marsh interface, snails not present. 5 - Non-habitat, snails present. 6 - Non-habitat, snails not present.

Plate 1C. F. bulimoides habitat model, extrapolated to a larger study area within the Cameron-Creole Watershed, overlain on the soil map. Soil key (Color/letter code for Plate 1A applies): C - Creole; M - Mermentau; P - Peveto; H - Hackberry; X - Hackberry-Mermentau complex; S - Open water; W - Scat Lake and other soil series of deep marsh; A - Predicted habitat of F. bulimoides. The rectangle indicates the approximate location of the of the initial study farm.

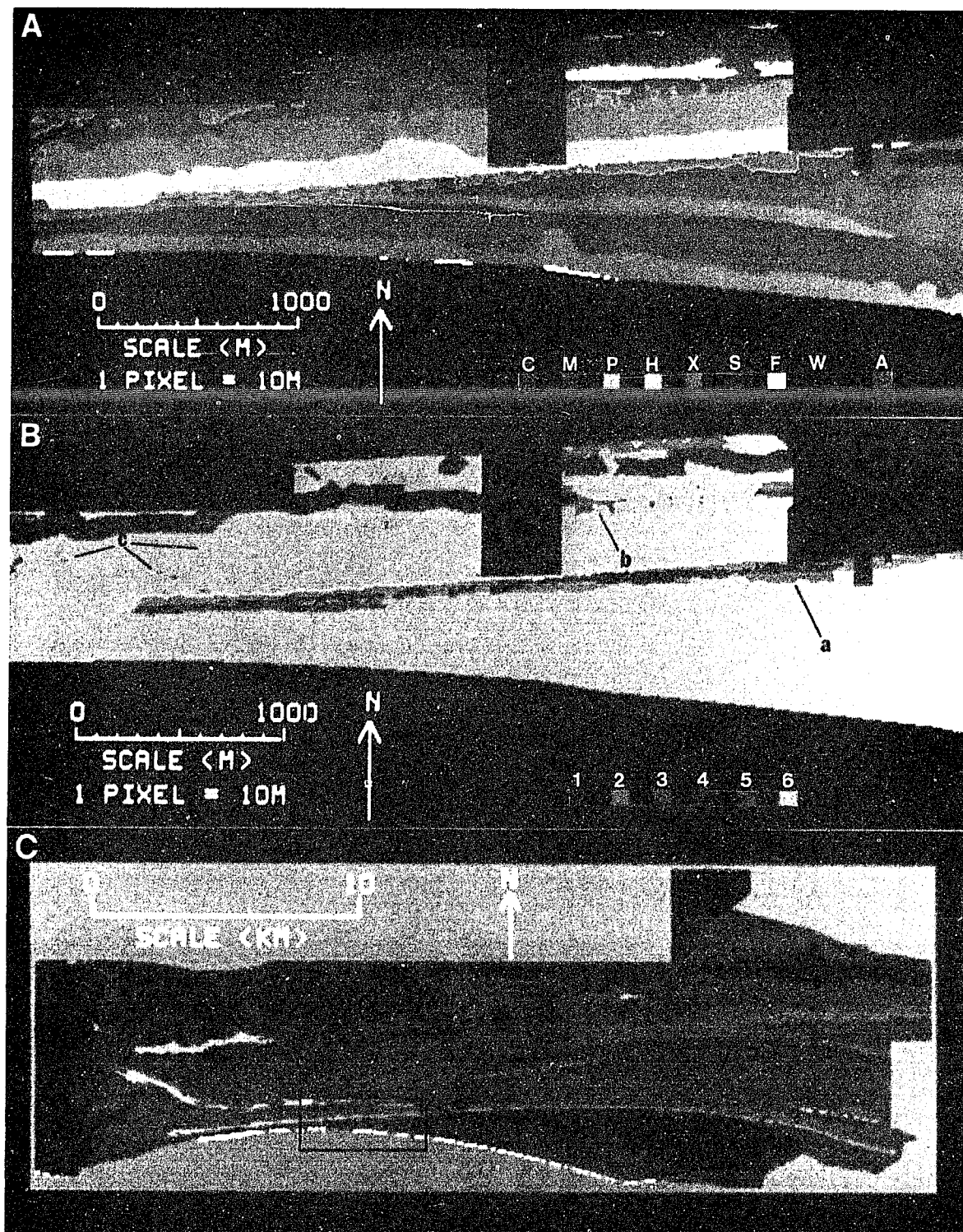


Fig 1- Diagram of the primary study farm showing features discussed. Cross-hatched areas indicate marsh; soil interfaces correspond to those shown in Plate 1a. A through G: Foci of habitat. A - on waveface of Front Ridge at the marsh interface; B - on backslope of Front Ridge at the marsh interface; C - on the backslope of a minor ridge; D - on interface of Mermentau series with Hackberry-Mermentau complex on the ridge; E - Largest focus in the north unit, between a soil interface and a slough; F - along the slough; G - on interface of Hackberry series and Hackberry-Mermentau complex on the ridge; H - within the Hackberry-Mermentau Complex on the backslope. T-T' - Transect along the fenceline separating the west unit from the others. Inset: Diagram of topography along transect T-T', demonstrating relationships between elevations and features observed. Soil series: C - Creole; M - Mermentau; H - Hackberry; X - Hackberry-Mermentau complex; P - Peveto; F - Felicity. Features: MR - minor ridge; S - slough; BS - backslope; RT - ridgetop; WF - waveface.

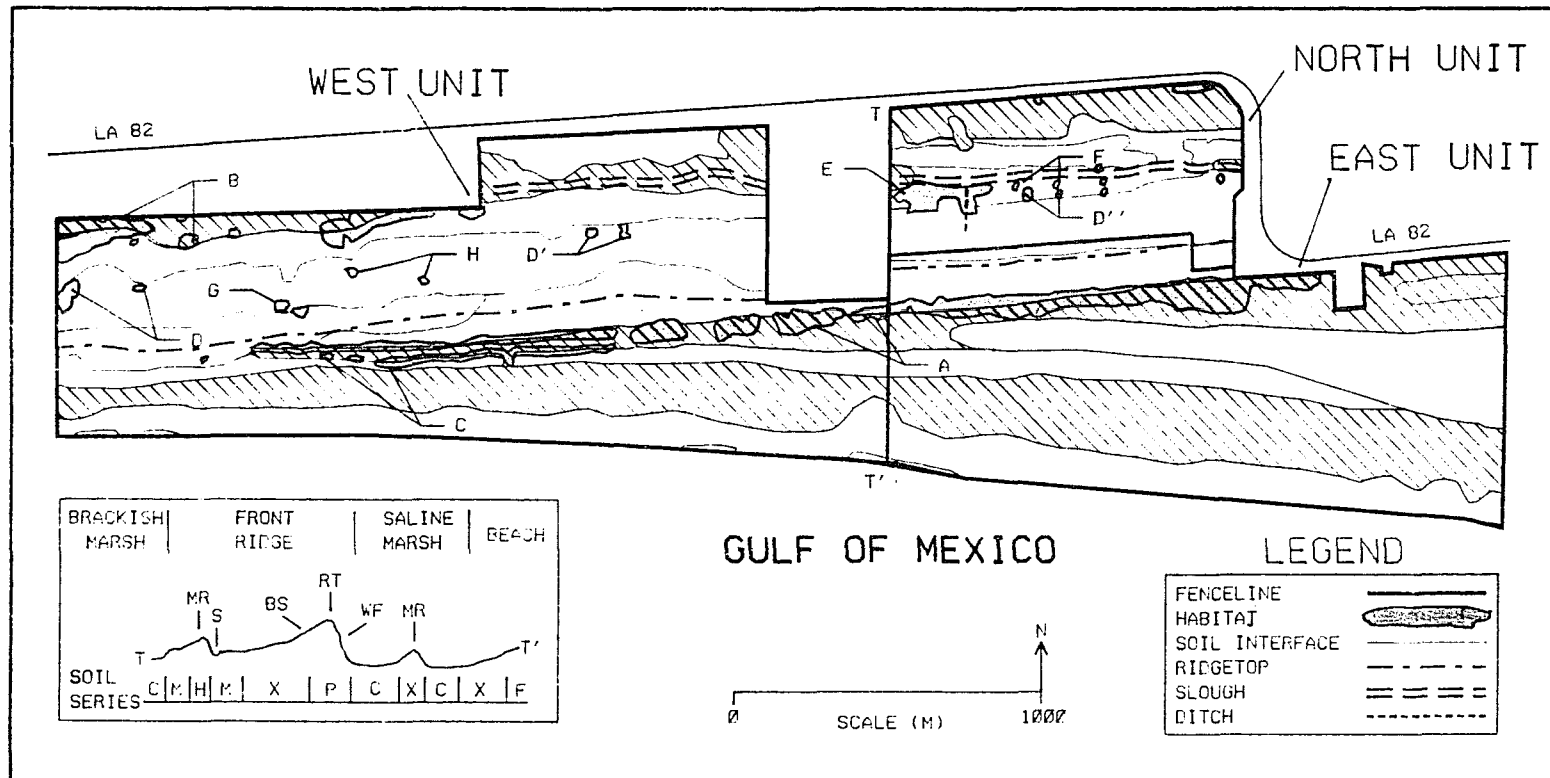
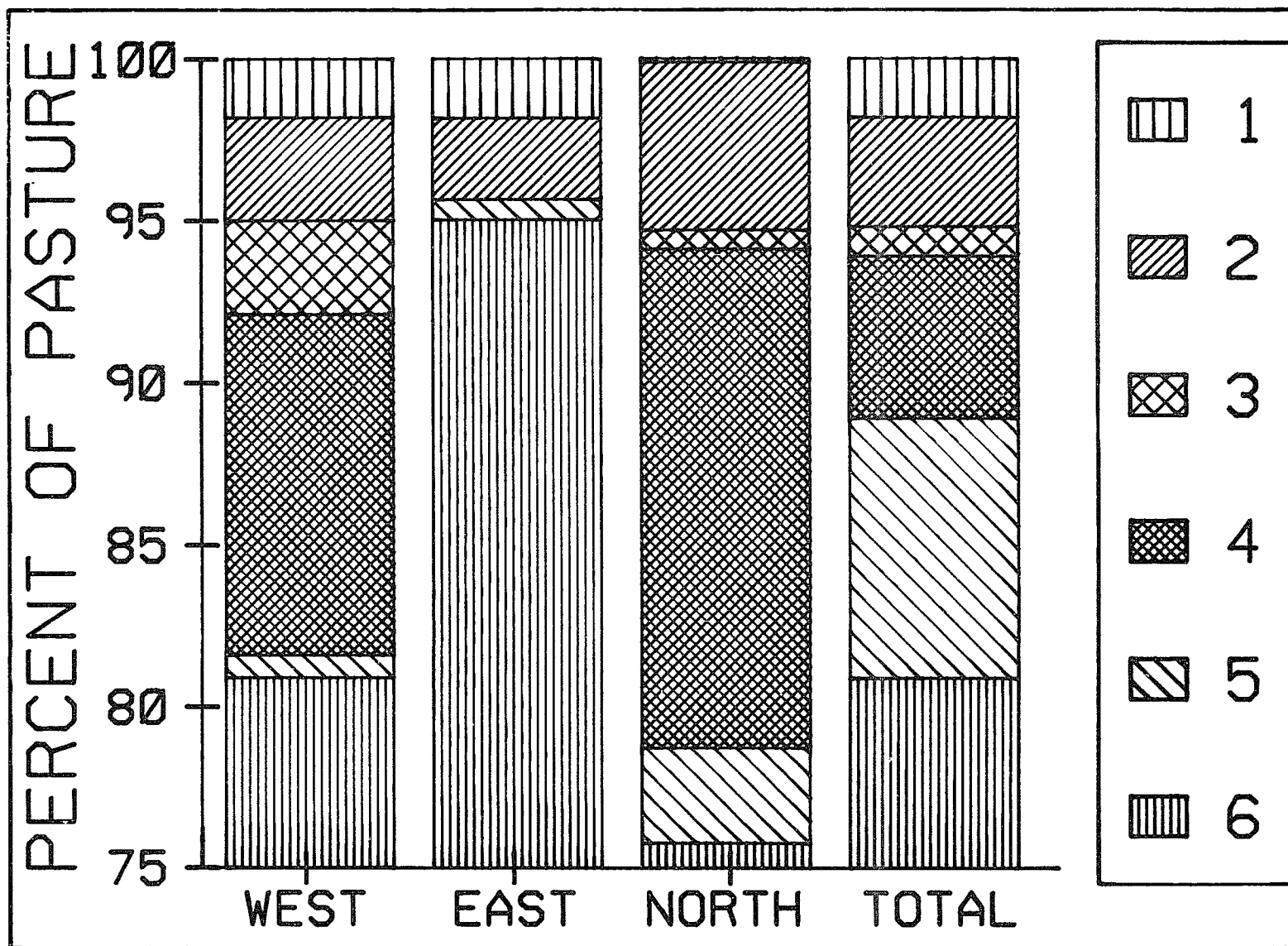


Fig 2- Comparison of simulated and actual habitat on the primary study farm and management units. Key to classifications^{*}: 1 - Waveface at chenier-marsh interface, snails present. 2 - Waveface at chenier-marsh interface, snails not present. 3 - Backslope at chenier-marsh interface, snails present. 4 - Backslope at chenier-marsh interface, snails not present. 5 - Non-habitat, snails present. 6 - Non-habitat, snails not present.

^{*}Classifications correspond to those for Plate 1b.



From the Department of Veterinary Microbiology and Parasitology (Zukowski, Malone) and Remote Sensing and Image Processing Laboratory (Hill), Louisiana State University, Baton Rouge, LA 70803.

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This report represents a portion of a thesis to be submitted in partial fulfillment of the requirements for the Ph.D. degree.

Presented in part at the 12th Congress of the World Association for the Advancement of Veterinary Parasitology, Montreal, Quebec, Canada, August 12-15, 1987.

FOOTNOTES

^aPerkin-Elmer Model 8/32. Perkin Elmer Computer Systems Division,
Ocean Port, NJ.

^bTurnipseed DP. Spatial and Temporal Analysis of Coastal Wetland
Loss with Remote Sensing. M.S. Thesis, Louisiana State
University, May 1986. 101pp.

^cGulf Coast Aerial Mapping Co., Baton Rouge, LA.

^dZeiss RMK-A-15/23, Carl Zeiss, Oberkochen.

^eKodak 2405XX Aerographic Film, Eastman Kodak Co., Rochester, NY.

^fKodabrome II-RC, Eastman Kodak Co., Rochester, NY.

^gStereo Zoom Transfer Scope. Bausch & Lomb, Inc., Rochester, NY.

^hTalos Model RP648B. Talos Systems, Inc., Scottsdale, AZ.

ⁱBecker RC, Baton Rouge, LA: Personal communication, 1985.

Manuscript II. Fasciola hepatica: USE OF SOIL MAPS IN A GEOGRAPHIC
INFORMATION SYSTEM TO INDICATE SNAIL HOST HABITAT DISTRIBUTION ON
LOUISIANA COASTAL RANGES

Stanley H. Zukowski, D.V.M.; Farrell W. Jones, M.S.;

John B. Malone, D.V.M., Ph.D.

Keywords: Paramphistomum microbothrioides; F. hepatica; cattle;
Fossaria (Lymnaea) bulimoides; habitat; soil map; model; geographic
information system; risk assessment.

SUMMARY

A geographic information system model was used to test the hypothesis that distribution of Fossaria bulimoides follows interfaces of chenier and marsh soils on the Chenier Plain of Louisiana. Snail surveys were done on transects over three strata on 12 farms: 1) waveface (WF, former beachfront), 2) backslope (BS) chenier-marsh interfaces, and 3) chenier (relict beaches, above their interfaces with marsh). Twenty three per cent of snail habitat was found on chenier-marsh interfaces, most of this along interfaces adjacent to relatively broad cheniers; 61% of snail habitat occurred within the Hackberry-Mermentau (Hm) complex of soil series on cheniers above interfaces. An additional 14% of habitat occurred on soils of the Mermentau series, and 2% was found on marsh adjacent to interfaces with chenier. The proportion of farm occupied by F. bulimoides habitat regressed significantly against the proportion of farm comprised of Hm soil ($p = 0.024$, $r^2 = 0.416$, slope = 0.165). Results indicate that a successful soil-based model for estimation of snail habitat distribution on the chenier plain region should include the area of soils of the Hackberry-Mermentau complex as well as the interfaces of marsh and cheniers.

On the Gulf Coast, Fossaria bulimoides transmits both the liver fluke, Fasciola hepatica⁷, and Paramphistomum microbothrioides.^{45,47} Liver fluke disease plagues cattle producers wherever snail intermediate host species occur. The rumen fluke is seldom implicated in disease in the United States. Climate risk forecasts of fluke disease in Louisiana, based on a moisture-accounting system and summation of growing degree days, reflect a 100-fold variability between years in seasonal fascioliasis risk as measured by counting flukes recovered from tracer steers on pasture. The forecasts have been used in Louisiana to provide timely treatment advisories on a regional basis to producers^{1,50,52}. However, at least as much variability occurs between individual farms in a climate region as between years². Malone and Craig have proposed the need for a more comprehensive model of fascioliasis, comprised of 4 elements: 1) the climate model of life cycle development; 2) an estimate of habitat-related individual farm risk; 3) management-related factors, including treatment history, herd age structure, forage availability, pasture rotation, etc.; and 4) an economic risk component, related to market conditions and cost-benefit analysis.³

A geographic information system (GIS) has been defined as a decision support system involving the integration of spatially referenced data in a problem-solving environment.²⁷ It uses computer mapping technology to attach a data base to cartographic representations of geographic features (points, lines or polygons). A thematic map (representing one type of feature) forms one overlay (level of mapped data) in the computer. Operations can be performed

on single or multiple overlays to generate new overlays conveying novel information.

In the Chenier Plain of southwestern Louisiana, broad expanses of coastal marsh nest between a series of narrow relict landlocked beaches (cheniers). Soils contrast strikingly, with loose sands juxtaposed to heavy, gleyed clays⁵³. In a previous study on a 760 ha farm adjacent to the Gulf of Mexico, taken as representative of the region, F. bulimoides habitat clustered along chenier-marsh interfaces. Habitat was found more consistently along waveface (former beachfront) than along backslope. A few small foci occurred on the chenier above interfaces; little habitat occurred on marsh, and that only near interfaces. A geographic information system was used to compare maps of soil and snail habitat, and to generate an empirical model of snail habitat distribution on the 760 ha farm. Model habitat occupied bands 50-90 m wide at interfaces of marsh and chenier soil series. The model was extrapolated to a 29,000 ha study area.^a

The objective of studies reported here was to verify this model by surveys of snail habitat distribution on 12 additional farms in the chenier plain region.

Materials and Methods.

Study sites - Twelve farms, totaling 798 ha, were selected to test the model. Fig 1 shows the locations of the farms. Table 1 gives the taxonomic classification of their soils. Three farms (2A,

2B and 3E) were surveyed for snail habitat between February 2 and April 15, 1987. (Only the western pasture of farm 2A, where cattle were ranged at the time of the survey, was examined for habitat). Ten farms (3A - 3J) were surveyed between March 3 and April 28, 1988. (Farm 3E was surveyed 3 times: once before snail activity began and again after the onset of summer drought in 1987, and yet again during the period of snail activity in the spring of 1988.) Each farm was surveyed once over a period of 2 - 5 days during the season of snail activity. This season spanned the period from resumption of snail activity with spring warming, through population bloom to decline upon onset of summer drought, so that farms were not necessarily surveyed at comparable phases of snail population growth and dispersion.

Aerial photography - Panchromatic (black and white) aerial photography of the extended study area, acquired from November to December 1981 for the National High Altitude Program and enlarged to a scale of 1:12,000, was purchased from the National Cartographic Information Center and used in the field for orientation and for recording locations of observations.

Sample point allocation - On the 3 farms surveyed in the spring of 1987, interfaces were treated as linear transects and sampled at 30 m (40 paces) intervals. On farm 3E and the 9 new farms in the spring of 1988, snail surveys were made on three strata: 1) the waveface (WF) and 2) backslope (BS) chenier-marsh interfaces, and 3) chenier above interfaces.

To determine the sampling interval (m) for the WF and BS interface strata, the total linear extent (mm) of WF interface on a farm was estimated by measurements on the aerial photograph, then multiplied by the scale factor (12,000) and divided by 30.

To allocate sample points on the chenier above interfaces, a 'W' pattern was traced over the chenier on each pasture and its length measured on the aerial photograph. If more than 1 pasture held chenier, sample points were allocated between them as follows. The area of chenier on each pasture was estimated by Euclidian geometry from measurements on the aerial photographs; areas were summed to estimate total chenier area on the farm. Area of chenier in each pasture was divided by total chenier area, giving proportion of total chenier occurring on each pasture. For each pasture, this proportion was multiplied by 30, giving the number of sample points allocated to the pasture. The length of the 'W' pattern on each pasture was divided by the number of sample points allocated to the pasture, giving the sampling interval for the pasture.

An all-terrain vehicle (ATV) was used for sampling. A spring was attached to the front wheel and a striker attached to the fork, so that each revolution of the wheel produced a sound. Sampling interval (m) was divided by tire circumference, and in the field distance along transects was determined by counting wheel revolutions.

Point sampling procedure - During the spring, 1987 survey an area of approximately one square meter was searched for one minute at each sample point for presence of snails. During the spring,

1988 survey a $1/2 \text{ m}^2$ frame was thrown over the shoulder on the ATV at each sample point. Presence or absence of snails within the frame where it fell was determined by one or both of 2 methods. The first was by searching within the frame for 1 minute. The second, used only in the presence of sufficient water, was by use of a wire screen coffee strainer, rotated about its longitudinal axis in a hoofprint or other depression and then lifted to scoop any snails. Where at least one snail was encountered, the limits of the snail habitat were determined by additional searches and then traced onto the aerial photograph. The described transects represent the minimal standard search methodology used in this study; in addition, the mobility provided by the ATV was utilized to ensure that any moist areas suitable for snail propagation were discovered and searched for snails. Any habitat found was traced onto the aerial photography.

Geographic information system - The GIS used for this study included a computer-aided design system^b with associated mapping software^c and a database^d operating on a minicomputer^e. The raster-based model of habitat was converted to vector format and entered as one overlay. Data traced onto the aerial photographs was registered by use of "rubber-sheeting" software^f and entered as overlays for farm boundaries, habitat areas and point observations. Data compilation and statistical analysis were accomplished using a statistical software package^g.

Results.

Fig 2 through 9 show habitat superimposed on the soil map for each farm. Table 2 and Fig 10 summarize soil and habitat areas for each farm in the study. Mapped habitat occupied 1.90% of the total area of all farms. Habitat was found on 11 of the 12 farms, occupying up to 18.4% of the area of a farm (farm 3J, Fig 2).

Snail habitat was found on or adjacent to chenier-marsh interfaces, as predicted. However, such habitat seldom occurred except along interfaces with certain topological relationships. First, habitat occurred along interfaces of marsh with wavefaces of chenier soils, but only where the chenier was relatively broad compared to the interface zones (Fig 2, 3 and 4, points a). In the farms sampled in this study, the chenier soils involved in this topology were of the Hackberry-Mermentau complex of soil series (HM). Examination of the soil and habitat maps suggests a dichotomous classification of cheniers as "broad" or "narrow", with a cutoff around 50 m in width of chenier above any interface zones (Fig 3 and 4); there was much interface on chenier of lesser breadth lacking snail habitat (Fig 4, 5 and 6, points b).

Second, habitat occurred along backslope interfaces of marsh with chenier soils of the Mermentau series. However, this again occurred only where the Mermentau series soils lay at the foot of a broad chenier. Two of the 3 instances of this topology in this study involved chenier with soil of the Peveto series at the top of the chenier (Fig 5 and 7, points c), as had been seen at the primary study site. The third instance involved the backslope of a broad HM chenier (Fig 4. point c). Much interface of marsh with soil of the

Mermentau series occurred on lesser cheniers, but held no snail habitat (Fig 3, 4, 5, 6, 7 and 8, points d).

Overall, model interfaces along wavefaces occupied 5.25% of the farms in the sample and accounted for 1.82% of the surveyed habitat. Model interfaces along backslopes occupied 12.67% of the farms in the sample and accounted for 21.69% of surveyed habitat (Table 1).

In addition to the interface habitat of the model, considerable additional snail habitat was found in or along moist areas within the Hackberry-Mermentau (HM) soil series complex on cheniers above interfaces with marsh. HM soil occupied 12.32% of the area of the farms in the sample and accounted for 61.39% of all surveyed habitat (Table 1), a considerably higher proportion than that found at the primary study farm used to develop the model. Again, this habitat was limited to broad cheniers (Fig 2 - 7, points e). Such habitat was found in or along natural or anthropogenic moist depressions. Regression analysis of percentage of farm comprised of habitat against percentage of farm comprised of HM soils suggested that approximately 40% of habitat distribution is explained by HM soil alone (Table 2, Fig 11).

A small percentage of habitat occurred in a few other sites. A third interface topology, not included in the model, occasionally held snail habitat. This was waveface or backslope interfaces of HM with Mermentau series soils (again, limited to broad cheniers; Fig 3, 4, 5, 8 and 9, points f). On farm 3E, habitat was found on Me soil (Fig 3, point g). This habitat occupied a "blowout", a site where wave action had breached the ridge at some time in the past and left a linear depression perpendicular to the main axis of the

chenier which tended to hold water. On farms 3B and 3F, habitat was found on soil of the Mermentau series around leaking water troughs, and on farm 3C habitat occurred along the backslope interface of a narrow HM chenier (Fig 4 and 5, points g). The latter site occurred on either side of a low point on the chenier where there was seepage of water between 2 bodies of marsh soils. Habitat on farm 3H likewise occupied a low point on a narrow ridge through which water drained onto the marsh (Fig 5, point g). On farms 3D and 3I, habitat occurred on soil of the Mermentau series on and about the edges of barrow pits (Fig 7 and 9, points g).

Discussion.

The current study focuses on use of a soil map as an indicator of potential habitat of the snail host of F. hepatica on individual farms over a broad geographic region. Potential habitat for F. bulimoides is defined here as ground which under suitable climatic conditions can be colonized by the snail. It is the area which might be associated with risk of transmission of snail-borne disease agents. Estimates of a general nature (e.g.: risk categories I - IV) would likely be sufficient for use in a comprehensive model of fascioliasis.

The hypothesis tested was that the distribution of snail habitat on a farm can be extrapolated from the empirical model of snail distribution. Ideally, the proportion of a farm comprised of habitat would depend on the proportion of the farm comprised of model habitat (computer-generated interface zones). It was

anticipated that waveface and backslope interface zones would differ in their relative contributions to actual habitat area. It was also anticipated that soils of the Hackberry-Mermentau complex would contribute some component of actual habitat.

Rosenfield, et al²³ developed a practical model for severity of human schistosomiasis based on linear extent of waterways serving as habitat for Bulinus truncatus. Their model permitted estimation of risk without requiring on-site surveys of habitat, and even allowed assessment of disease risk in areas of planned construction of new canals. Meek and Morris²⁴ developed a computer model of ovine fascioliasis which included the proportion of pasture occupied by snail habitat as one of many determinants of the severity of disease. Other determinants included egg contamination (itself influenced by adult fluke burdens of individual sheep and grazing patterns with respect to habitat) and anthelmintic administration. However, it provided no means of prediction of habitat area on unsurveyed farms. Wright and Swire²⁵ examined the relationship of Lymnaea truncatula habitat distribution in South Wales to mapped soil series. They were able to demonstrate a relative preference for wet sites within gleyed soils and suggested use of soil maps to evaluate risk qualitatively.

In the farms of this sample, habitat tended to occupy both waveface and backslope interfaces of broad cheniers, but not of narrow cheniers. Likewise, habitat clustered mainly within HM soils on broader cheniers. This phenomenon might result from accumulation of rainwater in the sandy layers of chenier soils, creating a

"waterhead" with seepage in depressions and at interfaces with marsh. Seepages are preferred habitat for lymnaeid species.^{4,5,6,67} Narrow cheniers might not accumulate water volume sufficient to generate seepage with rate and duration adequate to support snail activity.

At the primary study site, upon which the extrapolation model was based, habitat consistently occupied waveface interfaces of the Peveto series with marsh soils, at the edge of a broad chenier. Interface of that specific chenier soil with marsh was not observed in the current sample of farms. However, waveface interface of marsh with HM soils, which was observed in the present study, appears to be less consistently colonized by snails. At the primary study site, as on farms of the current sample, backslope interface of marsh and Mermentau soil series was colonized by snails where the chenier was broad. Within HM soils on the primary study site, foci of habitat occurred in low, wet areas. This finding was not sufficiently consistent on the primary study farm to warrant incorporation into the original model, but was confirmed by the current study. In the current study, the large fraction of total habitat occupying HM soils, which themselves comprised a relatively modest fraction of total farm area, as well as the moderate fit of habitat extent to HM extent in regression analysis, suggested that HM soil extent is a fairly good correlate with habitat extent.

Along with results from the primary study site, results of this study suggest refinements to 1) limit marsh-chenier interfaces in the model to those adjacent to broad chenier; 2) incorporate area of

broad chenier (HM, Peveto and perhaps Hackberry series) into the model; and 3) use aerial photography or remotely sensed data acquired during the season of snail activity to localize the moist, depressed areas on broad ridges and along their interfaces.

TABLE 1 - Taxonomic classifications of soils on the study farms.

SOIL SERIES	TAXONOMIC CLASSIFICATION (TO FAMILY)
<hr/>	
CHENIER SOIL SERIES	
Peveto (Pe)	Mixed, thermic typic udipsamments
Hackberry (Hb) ¹	Sandy, mixed, thermic aerice haplaquepts
Mermentau (Me) ¹	Clayey over loamy, montmorillonitic, non- acid, thermic typic haplaquepts
MARSH SOIL SERIES	
Creole (Cr)	Fine, montmorillonitic, non-acid, thermic typic hydraquents
Scat Lake (Sc)	Fine, montmorillonitic, non-acid, thermic typic hydraquents
<hr/>	

¹The Hackberry-Mermentau complex is recorded in areas where the Hackberry and Mermentau soil series intermingle or alternate in units too small to be mapped individually, in accordance with standard soil survey practice.

TABLE 2 - Analysis of variance for regression of proportion of farm occupied by surveyed habitat of F. bulimoides against proportion of farm comprised of soils of the Hackberry-Mermentau complex.

Source	DF	SS	MS	F	Prob > F
Model	1	141.4232	141.4232	7.118	0.0236
Error	10	198.6711	19.8671		
Total	11	340.0943			
<hr/>					
Root Mean Square Error			4.4573		
r^2			0.4158		
Slope			0.1650		
<hr/>					

Fig 1- Location of farms in the study area.

FOSSARIA BULIMOIDES HABITAT STUDY AREA

FARM IDENTIFICATION AND POSITIONS

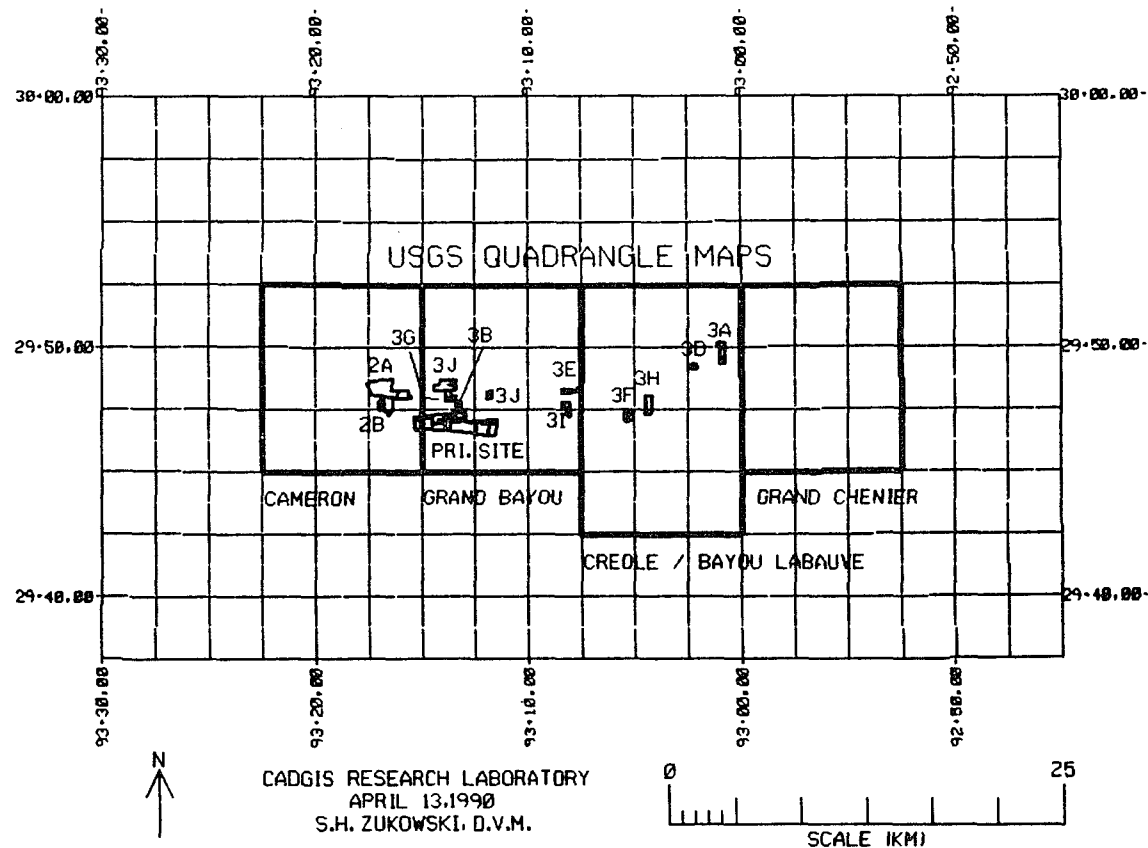


Fig 2- Soil and habitat map of Farm 3J. Key to coding: HM - Hackberry-Mermentau Complex. ME - Mermentau Series. IF - Model interface zone. HAB (Bold outline) - Surveyed habitat of F. bulimoides. a - Habitat along WF of broad chenier. e - Habitat in moist area within HM soils on broad chenier.

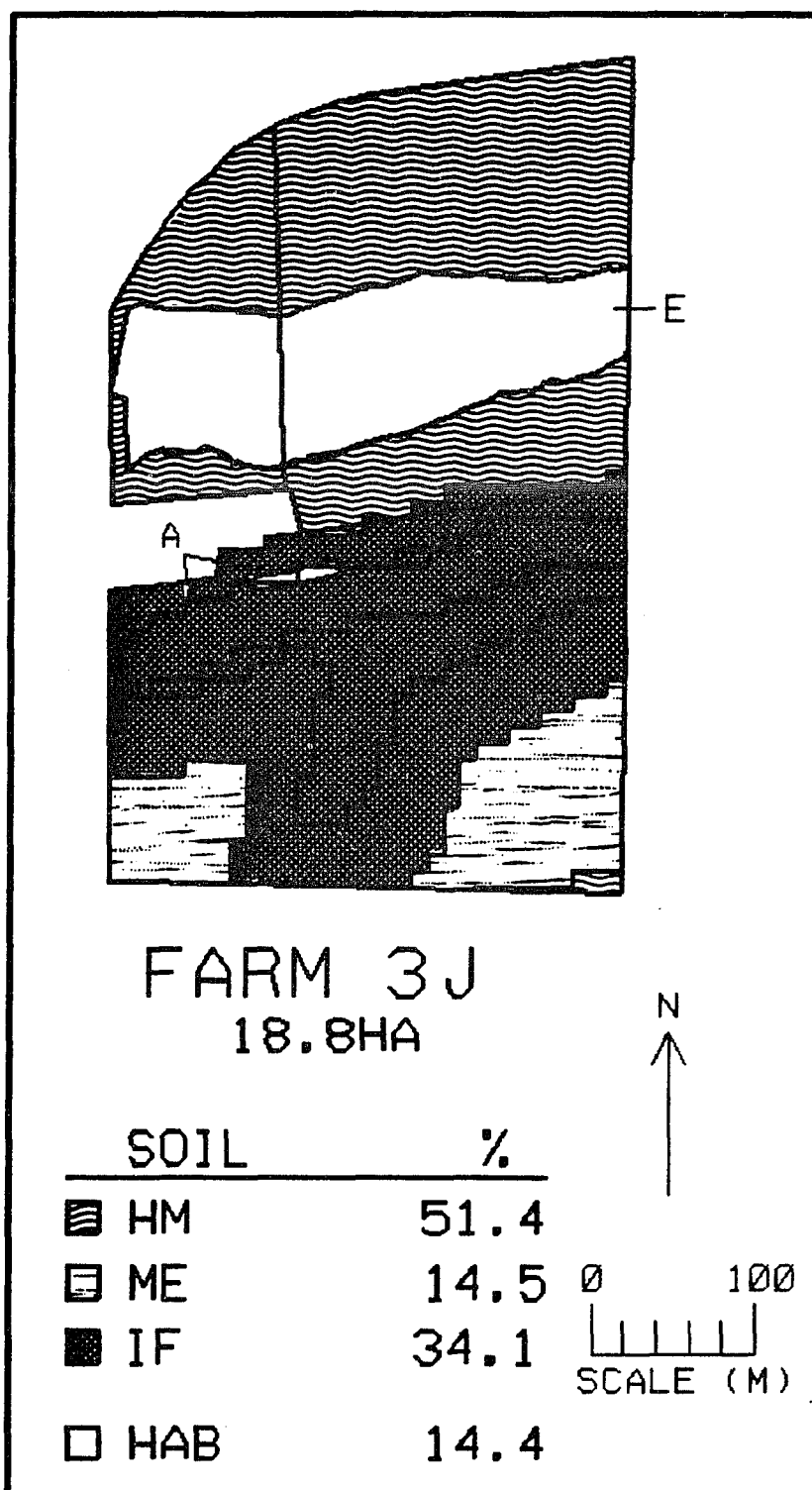


Fig 3- Soil and habitat map of Farm 3E. Key to coding: HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline - Surveyed habitat. a - Habitat along waveface of broad chenier. d - Narrow chenier lacking habitat at marsh-HM IF. e - Habitat in moist area within HM soils on broad chenier. f - Habitat along interface of HM and Me soils on broad chenier. g - Habitat on Me ("blowout").

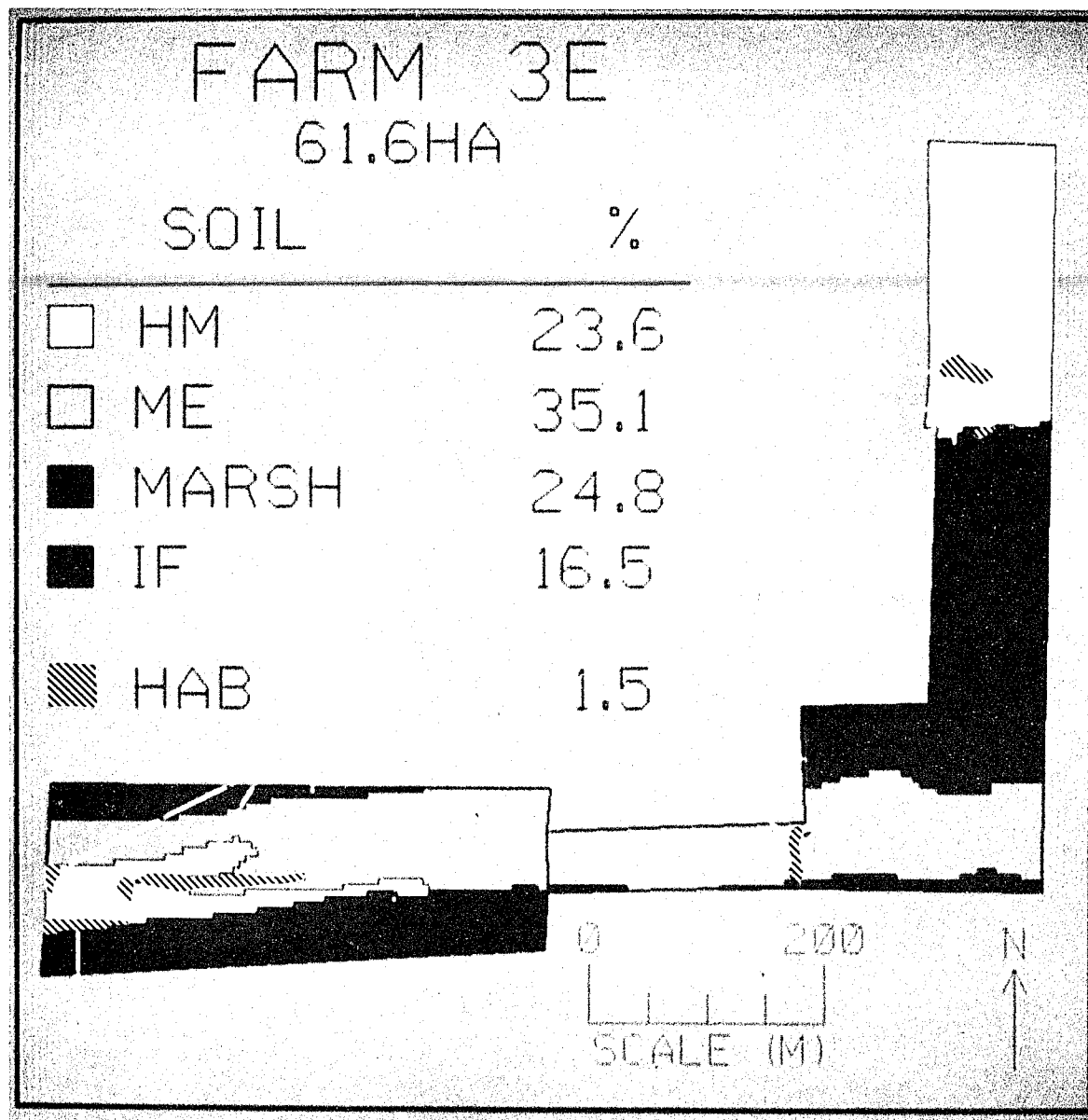


Fig 4~ Soil and habitat map of Farms 3B, 3C and 3G. Key to coding:
HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh -
Marsh soil Creole series). IF - Model interface zone. HAB (Bold
outline) - Surveyed habitat. a - Habitat along WF of broad chenier.
b - Narrow chenier lacking habitat at marsh-HM IF. d - Narrow
chenier, lacking habitat at marsh-Me IF. e - Habitat in moist area
within HM soils on broad chenier. f - Habitat along interface of HM
and Me soils on broad chenier. g - Habitat at anomalous site
(leaking water trough, farm 3B; low point in narrow chenier, farm
3C).

FARM 3C

115.4HA

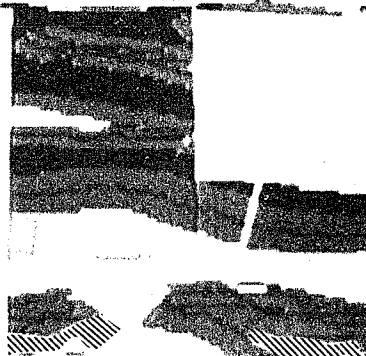
SOIL	%
HM	8.2
□ ME	31.0
■ MARSH	22.4
■ IF	38.4
▨ HAB	2.1



FARM 3G

47.1HA

SOIL	%
HM	14.2
□ ME	17.2
■ MARSH	15.9
■ IF	52.7
▨ HAB	2.9



FARM 3B

23.5HA

SOIL	%
HM	58.2
□ ME	25.2
■ MARSH	4.1
■ IF	12.5
▨ HAB	3.7

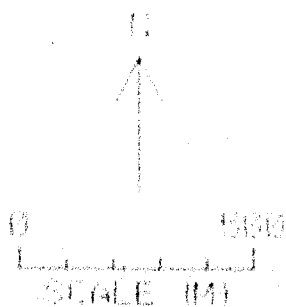
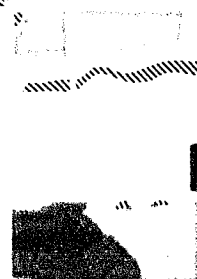


Fig 5- Soil and habitat map of Farms 3F and 3H. Key to coding:

Pe - Peveto series. HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline) - Surveyed habitat. b - Narrow chenier, lacking habitat at interface with marsh. c - Habitat at interface of marsh with Me on broad chenier with Pe at top. d - Interface of marsh and Me on narrow chenier, lacking habitat. e - Habitat in moist area within HM soils on broad chenier. f - Habitat along interface of HM and Me soils on broad chenier. g - Habitat at anomalous site (leaking water trough, farm 3F; low point in narrow chenier, farm 3H). Dashed lines - extension of soil boundaries between farms. h - narrow chenier. i - marsh.

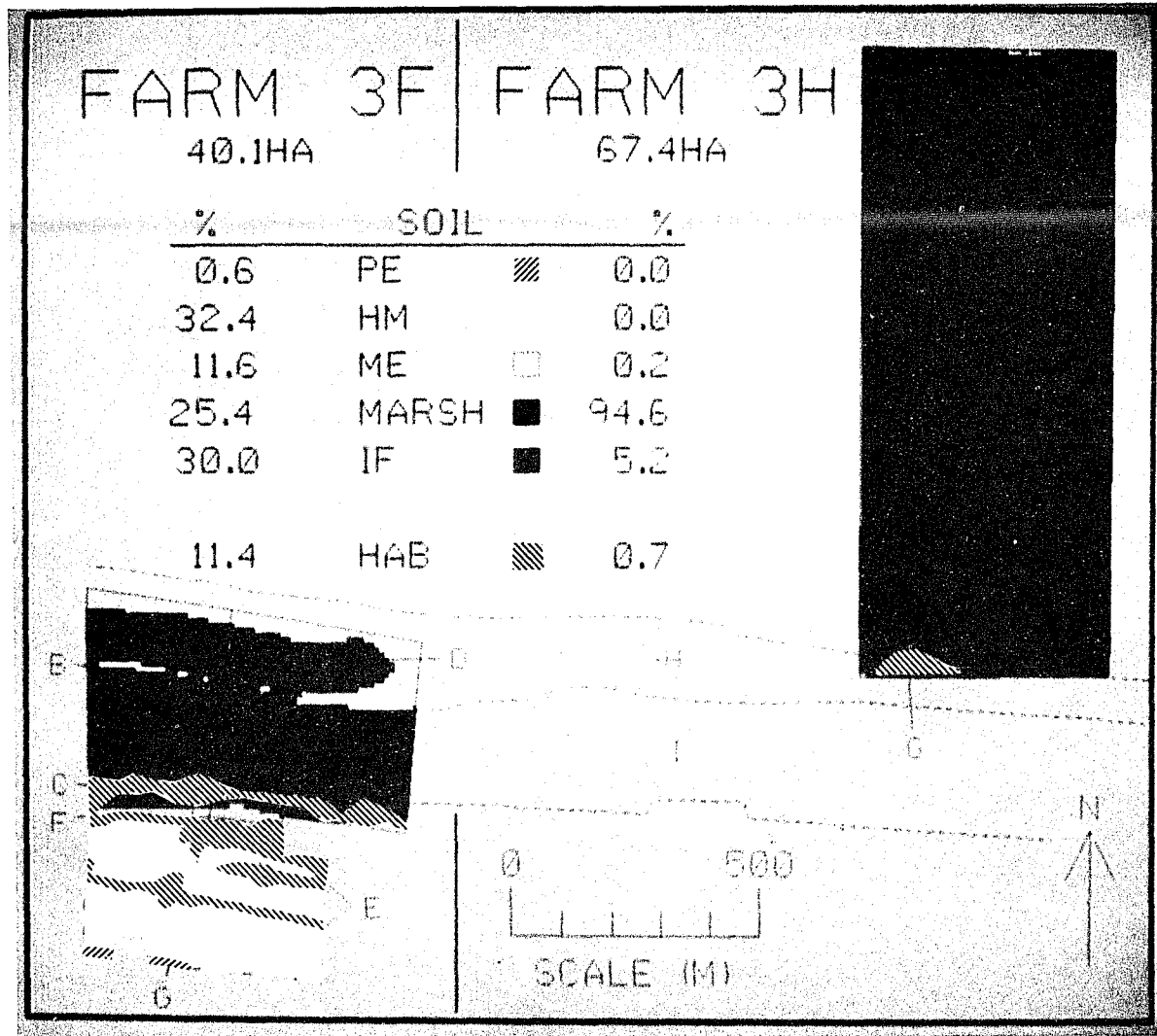


Fig 6- Soil and habitat map of Farms 2A and 2B. Key to coding:

Hb - Hackberry series. HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline) - Surveyed habitat. b - Narrow chenier lacking habitat at marsh-HM IF. e - Habitat in moist area within HM soils on broad chenier.

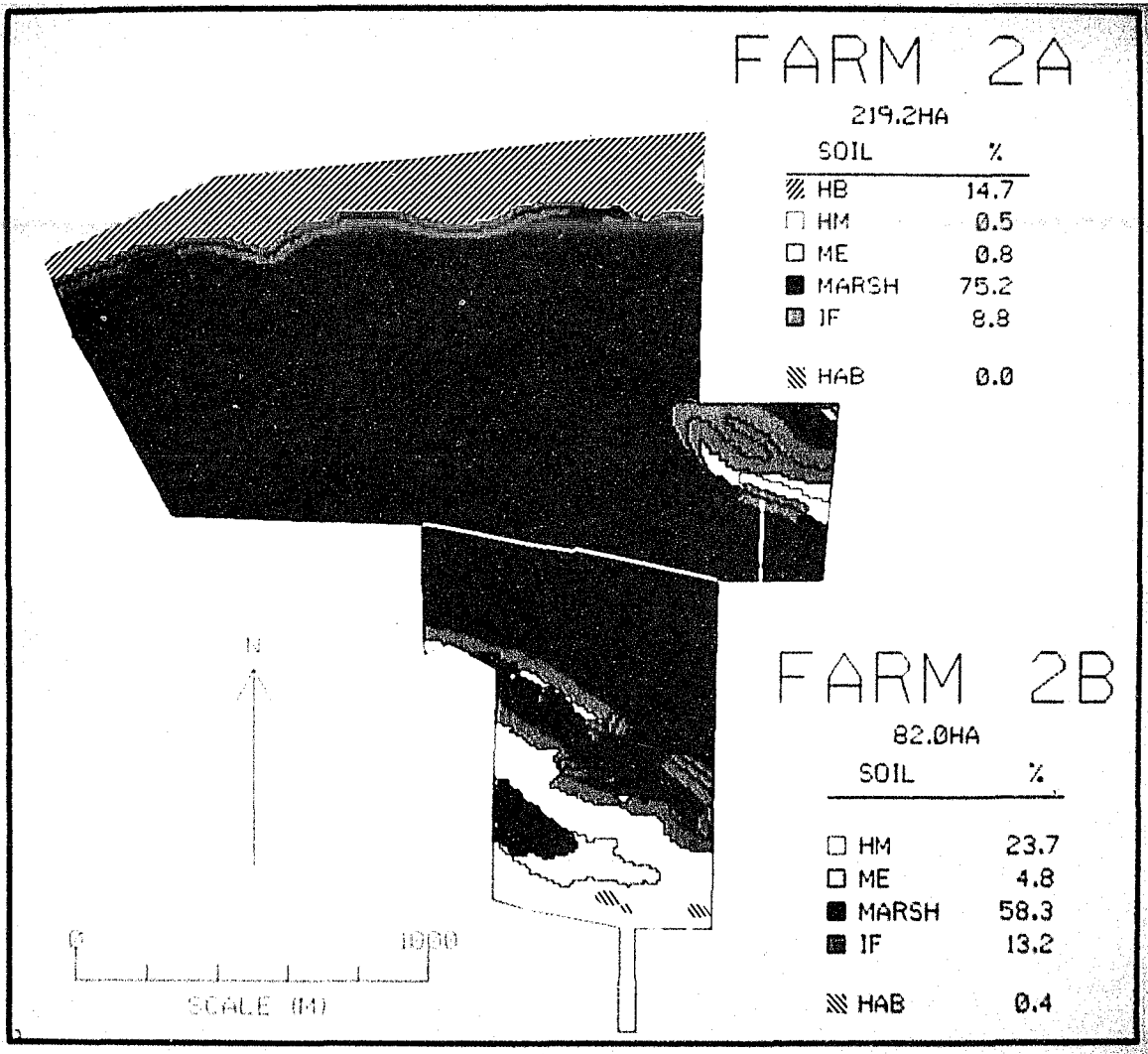


Fig 7- Soil and habitat map of Farms 3I. Key to coding: Pe - Peveto series. HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline) - Surveyed habitat. c - Habitat at marsh interface with Me below broad chenier, with Pe at top of chenier. d - Narrow chenier lacking habitat at marsh-Me IF. e - Habitat in moist area within HM soils on broad chenier. g - Habitat at anomalous site (barrow pit).

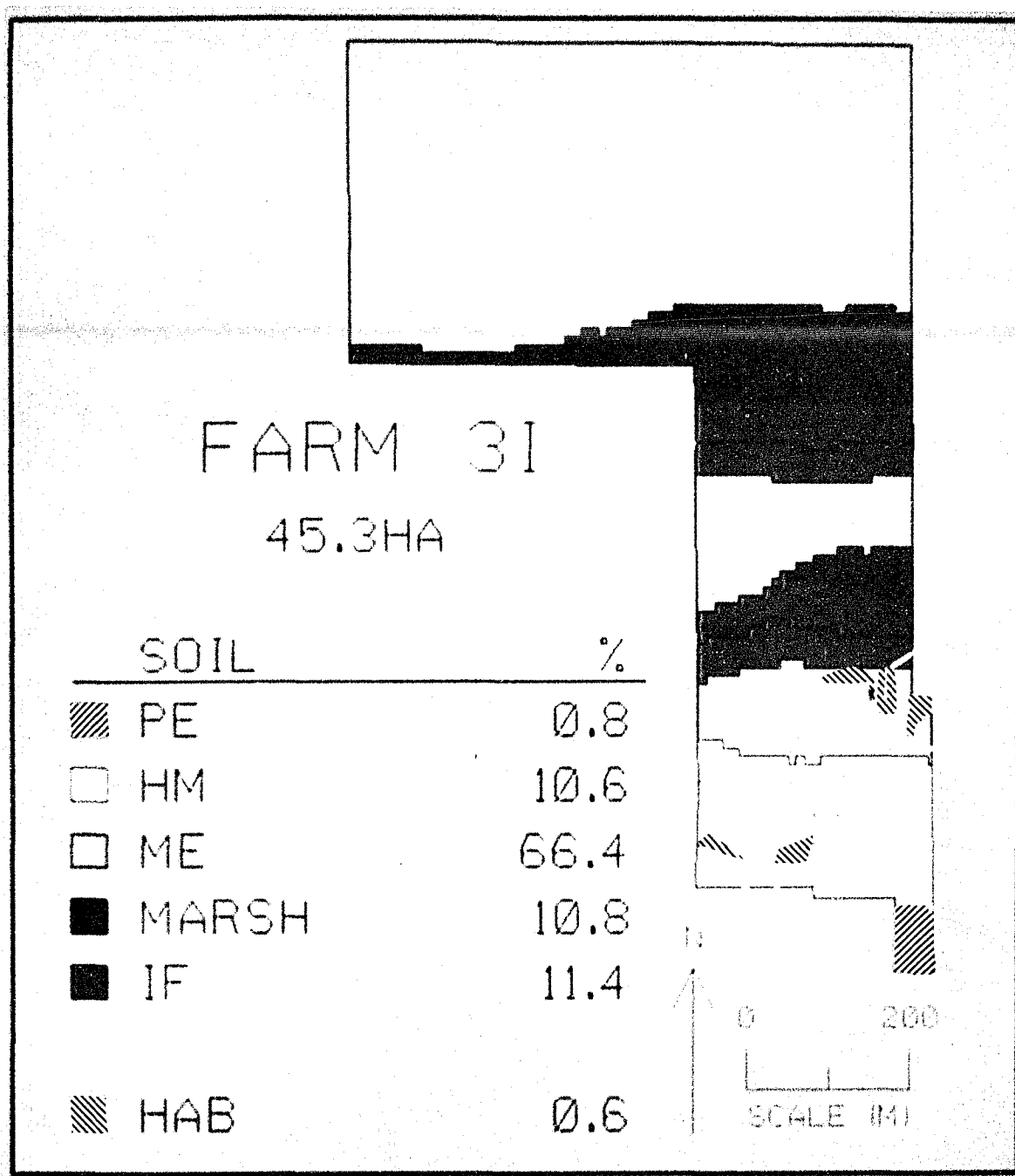


Fig 8- Soil and habitat map of Farm 3A. Key to coding: HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline) - Surveyed habitat. d - Interface of marsh and Me on narrow chenier, lacking habitat. e - Habitat on HM soil of broad chenier. f - Habitat along interface of HM and Me soils on broad chenier.

FARM 3A

68.6HA

SOIL %

<input type="checkbox"/>	HM	1.1
<input type="checkbox"/>	ME	5.4
<input checked="" type="checkbox"/>	MARSH	87.4
<input checked="" type="checkbox"/>	IF	6.0
<input checked="" type="checkbox"/>	HAB	0.8

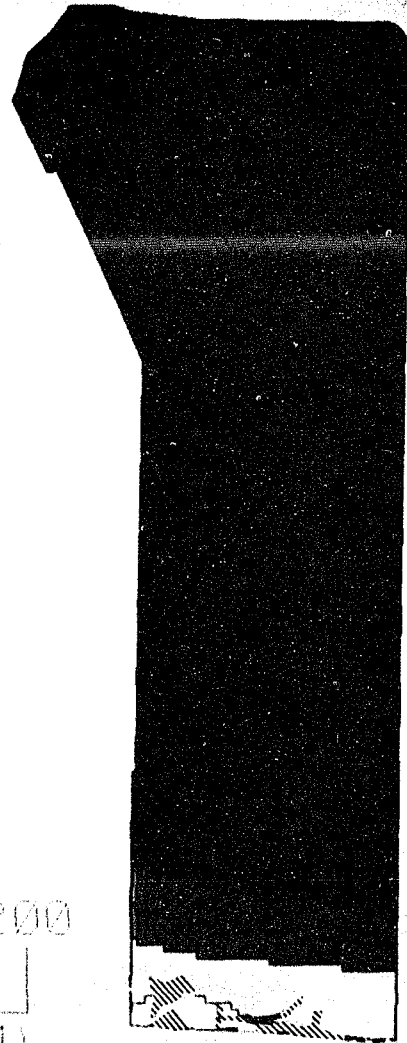
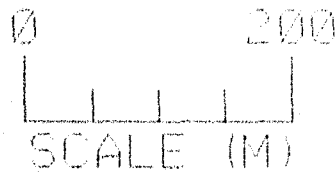
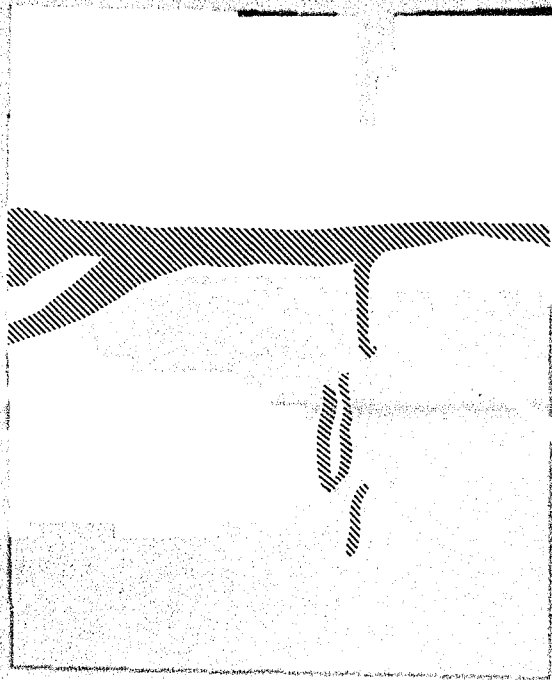
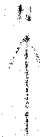


Fig 9- Soil and habitat map of Farm 3D. Key to coding: HM - Hackberry-Mermentau Complex. ME - Mermentau Series. Marsh - Marsh soil Creole series). IF - Model interface zone. HAB (Bold outline) - Surveyed habitat. f - Habitat along interface of HM and Me soils on broad chenier. g - Habitat at anomalous site (barrow pit).



0 100
SCALE (M)



FARM 3D
12.7HA

SOIL	%
HM	56.0
ME	43.7
IF	0.3
HAB	6.3

Fig 10- Proportion (%) of farm area occupied by surveyed habitat of F. bulimoides, by soil category. HM - Hackberry-Mermentau complex; Me - Mermentau series; IF - Model interface zones; Marsh - marsh soils.

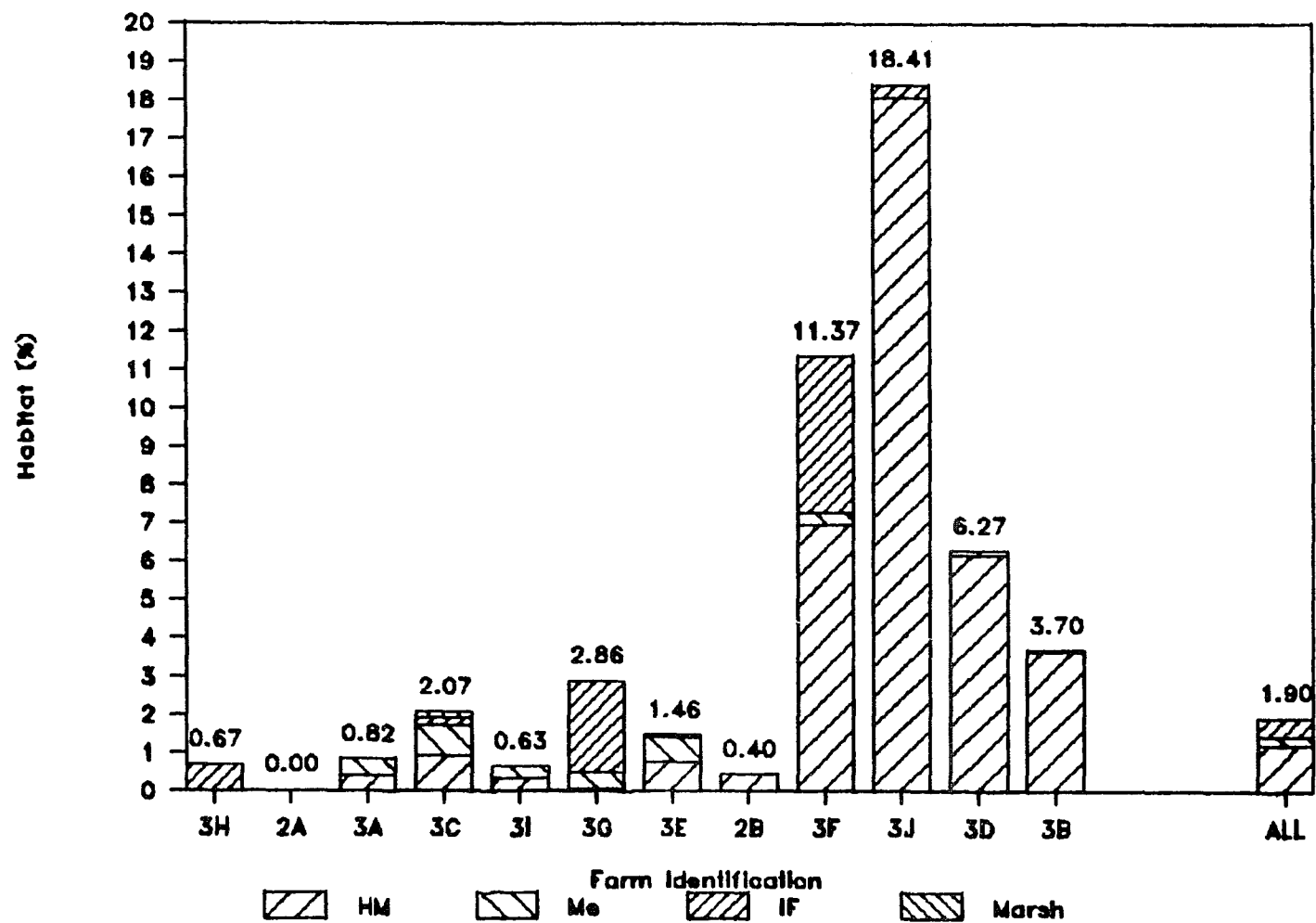
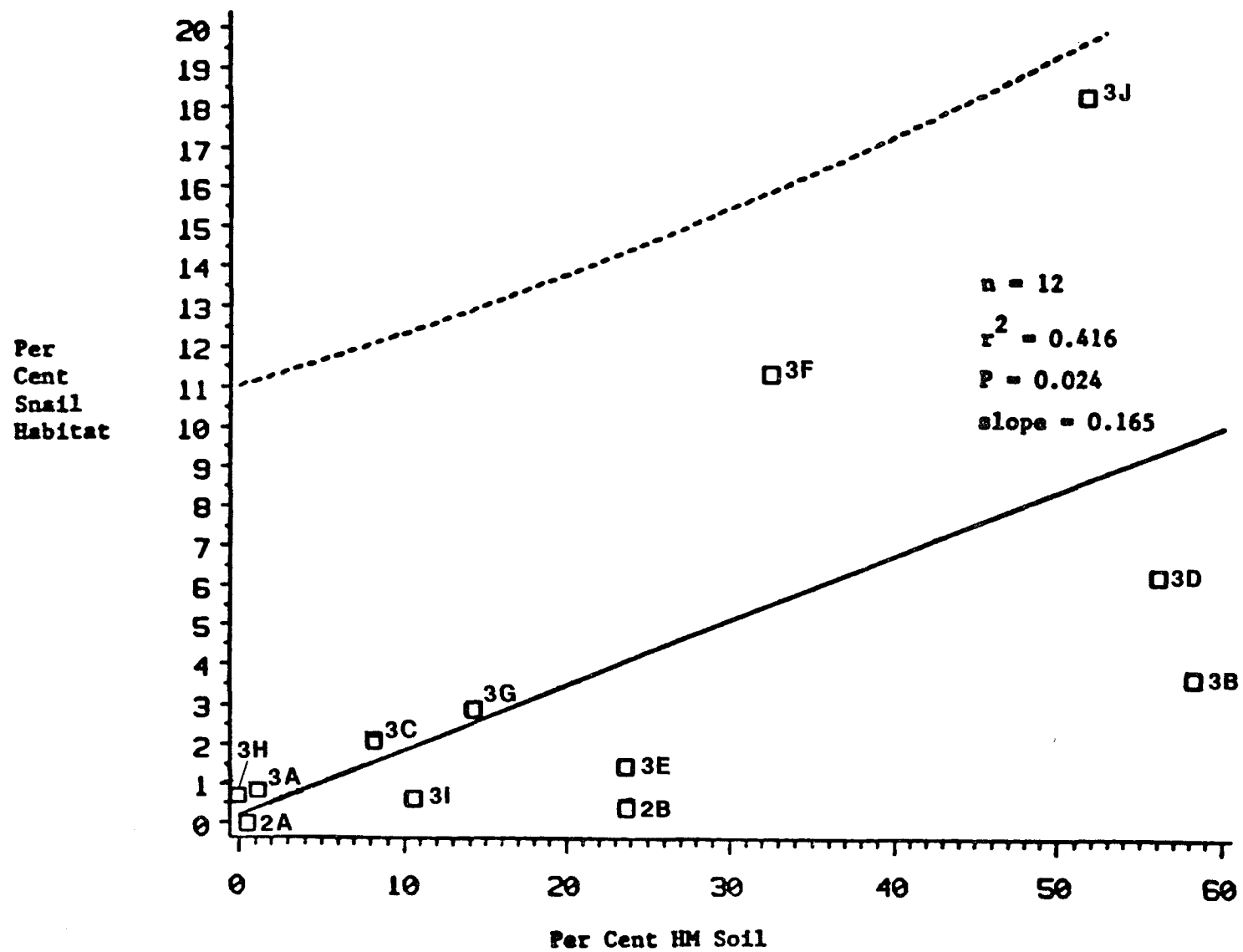


Fig 11- Regression plot of proportion of farm occupied by habitat of F. bulimoides (PCTHAB) against proportion of farm comprised of HM soils (PCTHM).



From the Department of Veterinary Microbiology and Parasitology (Zukowski, Malone) and Computer-Aided Design and Geographic Information Systems Laboratory (Jones), Louisiana State University, Baton Rouge, LA 70803.

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This report represents a portion of a thesis to be submitted in partial fulfillment of the requirements for the Ph.D. degree.

FOOTNOTES

^aZukowski, SH. 1990. Fascioliasis in cattle in Louisiana: Use of a geographic information system to develop a soil-based risk assessment model for habitat of the snail intermediate host, Fossaria bulimoides. Ph.D. Thesis, Louisiana State University.

^bInteractive Graphics Design System. Intergraph Corporation, Huntsville, Alabama.

^cWorld Mapping System. Intergraph Corporation, Huntsville, Alabama.

^dData Management and Retrieval Software. Intergraph Corporation, Huntsville, Alabama.

^eMicrovax II. Digital Equipment Corporation, Maynard, Massachusetts.

^fElastic Body Small Angle Least Squares. Intergraph Corporation, Huntsville, Alabama.

^gSAS System. SAS Institute Inc., Cary, North Carolina.

Manuscript III. GEOGRAPHIC INFORMATION SYSTEM FOR FASCIOLIASIS:
THE RELATIONSHIP OF FECAL EGG SHEDDING OF Fasciola hepatica AND
Paramphistomum microbothrioides IN CATTLE ON LOUISIANA COASTAL
RANGES TO Fossaria bulimoides HABITAT AS ESTIMATED BY SOIL MAPS

Stanley H. Zukowski, D.V.M.; John B. Malone, D.V.M., Ph.D.

Keywords: Fasciola hepatica; Paramphistomum microbothrioides;
cattle; Fossaria (Lymnaea) bulimoides; habitat; soil map; model;
geographic information system; risk assessment.

SUMMARY

A geographic information system was used to test the hypothesis that US Soil Conservation Service soil maps can be used to assess individual farm risk of fascioliasis in cattle in the Chenier Plain region of Louisiana. Although snail habitat had been localized to Hackberry-Mermentau soils and chenier-marsh interfaces on broad cheniers, no consistent relationship was shown in the present study between soils and fecal egg shedding by adult cattle on 7 to 10 farms over a 2 year period. Herd infection intensity indices based on fecal egg shedding (eggs per 2g * prevalence) were formulated for Fasciola hepatica and Paramphistomum microbothrioides, a rumen fluke transmitted by the same snail intermediate host, to test if rumen fluke egg shedding could be used as a surrogate for F. hepatica to account for the effect of flukeicide on treated herds. Rumen flukes are not affected by the flukeicide available in the United States at the time of this study. While similar trends in egg shedding for F. hepatica and P. microbothrioides were observed in untreated herds, a consistent correlation was not demonstrated.

Zukowski, et al reported that in the chenier plain of the United States Gulf Coast the distribution of habitat of Fossaria bulimoides, the snail intermediate host of Fasciola hepatica and Paramphistomum microbothrioides, follows the distribution of 1) the Hackberry-Mermentau complex of soils (HM) on broad cheniers and 2) interfaces of broad cheniers with marsh soils.^a The current study tests the hypothesis that the distribution of HM soils can be used to assess individual farm risk of fascioliasis as measured by fecal trematode egg shedding rates (assumed to reflect worm burdens) in resident cattle. Clorsulon^b, the only available flukeicide at the time of the study, produces marked reductions in F. hepatica egg shedding, but was not used uniformly across the farms. Since this drug has little efficacy against paramphistomes^{48,49}, P. microbothrioides egg shedding was investigated as a possible surrogate for F. hepatica egg shedding in assessing herd risk in recently treated herds.

Materials and Methods.

Study sites - Ten farms of a study reported elsewhere were used as study sites to test the relationship of F. hepatica and P. microbothrioides egg shedding to the extent of soil series previously reported to harbor most Fossaria bulimoides intermediate host habitat, using the GIS and data base described.^a

Quantitative fecal sedimentation - The prevalence and intensity of infection was evaluated by quantitative sedimentation of fecal samples (2g) from cows, collected from pasture (15 - 18 samples / herd) at 4 times: 1) Fall 1987 (September 13 - December 15); 2) June 17 - 18, 1988; 3) August 11 - 25, 1988; and March 3 - 5, 1989. The Fall 1987 samples were processed by a modification of the sedimentation method of Dennis, et al⁶⁸. All samples from 1988 and 1989 were processed by a sieving method similar to that of Ueno and Gutierrez^{69,b}. Processed samples were placed in petri dishes and examined under stereoscopic dissecting microscopes with artificial illumination. Results for P. microbothrioides were read with those for F. hepatica.

Determination of status of herds as treated or untreated -

Herds were assigned a status of "recently treated" against F. hepatica at the time of collection of fecal samples if they had received an effective flukeicide at a time that, according to published strategic control recommendations², would be expected to produce a marked reduction in egg shedding at the time of sample collection; that is, if they had not subsequently been exposed to major (spring⁶) fluke transmission on pasture within the 60-day prepatent period. Herds were classified as "recently treated" for the fall 1987 sample period if treated after May 1987; for the June 1988 sample period if treated after March 1988; for the August 1988 sample period if treated after May 1988; and for the March 1989 sample if treated after June 1988.

Body condition scores - Body condition scores were assessed for 15 or more cows per herd at the time of collection of fecal samples in March 1989. Condition was estimated on a scale of 0 (cachectic, moribund) to 10 (grossly obese), with a score of 7 assigned to an animal in excellent physical condition.⁵⁰

Soil model index - A composite variable termed the soil model index was formulated for each farm as follows:

$$(\text{area of HM soil} * \text{number of cows}) / (\text{total farm area}).$$

Statistical analysis - Data was compiled and analyzed using a commercial statistical software package.^c Fecal egg shedding rates for each herd were expressed as 1) mean eggs per 2g feces (EP2G); 2) egg shedding prevalence (%); 3) an egg shedding index (EP2G * prevalence); and 4) mean log (EP2G + 0.1), to normalize egg shedding distribution for use as a dependent variable in regression analysis. Regression analysis was performed for 1) log transformed P. microbothrioides (treated and untreated herds combined) and F. hepatica (untreated herds only) EP2G against the soil model index; 2) the egg shedding index of F. hepatica against the index for P. microbothrioides in untreated herds; and 3) mean herd body condition scores in March, 1989 against P. microbothrioides and F. hepatica egg shedding rates in August 1988.

Results.

Table 1 summarizes results for the study, giving farm identification, farm area, proportion of farm as HM soil, number of adult cows, soil model index, treatment status, fecal sedimentation results for Fall 1987, June 1988, August 1988, and March 1989, and mean body condition for March 1989. Fecal sedimentation results were not available for herd 3J in the fall of 1987, nor for herds 2A and 2B in June 1988, reducing the number of sample points with fecal sedimentation results to 9 and 8, respectively, for these sample periods. By March 1989 herds 2B, 3H and 3C had been dispersed, leaving 7 farms with body condition scores and fecal sedimentation results. Three of these herds had been treated with a flukeicide (clorsulon) during the fall of 1988. The soil model index varies with the number of cows on a farm; data are presented with farms ranked in order of soil model index values for June 1988 (shortly after the end of the season of F. hepatica transmission and completion of snail habitat surveys), when they varied from 0 to 15.9.

F. hepatica and P. microbothrioides egg shedding vs. soil model index - The F. hepatica egg shedding index in herds not recently treated ranged from 1.9 to 12.5 EP2G in the fall of 1987 (8 herds); 0.7 to 3.8 in June 1988 (5 herds); 1.2 to 61.9 in August 1988 (9 herds); and 2.9 to 5.4 in March 1989 (4 herds). Results are not reported for the few recently treated herds. The P. microbothrioides egg shedding index ranged from 0 to 7.5 in the fall

of 1987 (9 herds); 1.8 to 16.3 in June 1988 (8 herds); 0.1 to 35.9 in August 1988 (10 herds); and 0.6 to 22.8 in March 1989 (7 herds).

Fig 1a illustrates the relationship of P. microbothrioides egg shedding indices to the soil model index, and Fig 1b the relationship of F. hepatica egg shedding indices to the soil model index. There is an apparent trend of increasing P. microbothrioides egg shedding index with increasing soil model index values for the 4 sample periods. When tested by regression analysis, however, the trend was not significant for any of the 4 sample periods (Table 2). Similar statistical analysis for F. hepatica egg shedding, confounded by treatment effects, suggested no significant trend.

F. hepatica and P. microbothrioides mean egg shedding rates -

Results of regression analysis for fecal egg shedding of F. hepatica against P. microbothrioides in untreated herds are presented in Table 2. With the dependent variable being log transformed F. hepatica egg counts and the independent variable being either mean paramphistome egg counts or the paramphistome fecal egg shedding index (mean EP2G * prevalence), no significant correlation was found in any of the 4 sample periods. However, the untransformed F. hepatica and P. microbothrioides fecal egg shedding indices for untreated herds were significantly correlated with each other at the August 1988 sample period ($n = 8$, $r^2 = 0.59$, $p = 0.016$).

Fecal egg shedding and body condition - Results of regression analysis of mean body condition in March 1989 against P.

microbothrioides and F. hepatica egg shedding are presented in Table 4. Mean body condition in March 1989 was significantly correlated with mean paramphistome egg shedding in both August 1988 ($n = 7$, $r^2 = 0.72$, $p = 0.016$, slope = -0.09 ; Fig 2) and March 1989 ($n = 7$, $r^2 = 0.68$, $p = 0.023$, slope = -0.13). Also, mean body condition in March 1989 correlated with the paramphistome fecal egg shedding index for both August 1988 ($n = 7$, $r^2 = 0.70$, $p = 0.019$, slope = -0.09) and March 1989 ($n = 7$, $r^2 = 0.58$, $p = 0.46$, slope = -0.12). Among untreated herds, regression analysis of F. hepatica egg shedding against the soil model index suggested no significant trend.

Discussion.

Rosenfield, et al²³ developed a practical model for prevalence of human schistosomiasis based on linear extent of waterways serving as habitat for Bulinus truncatus. Their model permitted estimation of risk without requiring on-site surveys of habitat, and allowed assessment of disease risk in areas of planned construction of new canals. Meek and Morris²⁴ developed a computer model of ovine fascioliasis which included the proportion of pasture occupied by snail habitat as one of a number of determinants. However, it provided no means of estimating risk on unsurveyed farms. Wright and Swire²⁶ examined the relationship between distribution of Lymnaea truncatula in South Wales, and suggested that areas of gleyed soils were of qualitatively increased risk. Taken together,

these reports suggest that certain soils could be used to indicate potential habitat extent of lymnaeid snails.

Wilson and Taylor reported that variation in density of snails and miracidia can both affect the level of parasitization of the snail and influence transmission.²⁰ Interpreting this data, Boray stated that infection rates of snails at high miracidial density were lower than could be accounted for by considering dual infection of snails, indicating that individual susceptibility of snails was important.²¹ He presented laboratory data suggesting that with increased snail population density there were reductions in both snail infection rates and in metacercarial shedding rates. With a 40-fold increase in snail density, metacercarial production per habitat varied by less than 40%. In a second experiment he showed that at higher population densities the snails were smaller, associating reduced growth rate with reduced parasite burdens. A third experiment associated increased size, number and cercarial content of redia from snails given better nutrient conditions¹⁶; this is in agreement with earlier work by Kendall.²² Results indicate that habitat-related risk may not be heavily dependent on snail population density, leaving habitat area and productivity as 2 primary determinants of metacercarial production from snail habitat on a farm (habitat risk). This study focuses on the component of risk associated with areal extent of snail habitat.

The potential to map habitat-prone areas^d suggests that it may be possible to rank farms on fascioliasis risk using soil maps from the U.S. Soil Conservation Service. As in the model of Rosenfield,

et al, a method for ranking farms on risk of fluke disease based on the proportion of the farm comprised of HM soil might permit risk assessment for individual farms over a broad geographic area without requiring extensive on-site habitat surveys. For use with a regional climate forecast developed for Louisiana, snail intermediate host habitat risk estimates of a general nature (e.g.: individual farm habitat risk categories I - IV) would likely be sufficient for use in a comprehensive model.

Soil model index and fecal egg shedding — Although snail habitat on the chenier plain was earlier found to be localized in HM soils on broad cheniers and interfaces of broad cheniers and marsh^a, a significant relationship was not demonstrated in the present study between soils and fecal egg shedding of either F. hepatica or P. microbothrioides by adult cattle. This result may be explained by 1) the inherent inaccuracy of fecal egg shedding in cows, 2) a number of important management variables, 3) stochastic effects related to size of the farms and 4) limited sample size. There is no accepted statistical technique for regression analysis with repeated sampling.

Although a general relationship between average F. hepatica burdens and fecal egg shedding prevalence has been reported when used on a herd basis (10 to 15 samples per herd)³, considerable individual variation occurs, and the method is not a highly sensitive measure of risk. Variation of egg shedding with time of day⁴⁴ was not controlled in this study.

Management factors (in particular, stocking rate, nutrition, age structure of the herd^{d2} and flukeicide treatment) may have an effect on fecal egg shedding rates. The soil model index includes a factor for stocking rate. Farm 3A, with the second lowest soil model index, had notably high egg shedding rates for both F. hepatica and P. microbothrioides and the worst body condition scores. The owner attributed the poor condition of his cattle (Table 1) to detrimental effects on his marsh forage of a series of climatic events including drought, a freeze and flooding. The high egg shedding rates may have resulted from lowered resistance to parasitism of nutritionally stressed cattle. Two of the 12 herds in the previous study^a were comprised exclusively of heifers and were excluded from this analysis. The remaining 10 herds consisted of predominantly adult cows with varying proportions of replacement heifers; detailed age structure was not available. Flukeicide treatment was partially accounted for by eliminating recently treated herds from analyses involving F. hepatica egg shedding. Since F. bulimoides serves as intermediate host for both F. hepatica and P. microbothrioides, but P. microbothrioides is not affected by treatment with clorsulon, analyses for P. microbothrioides egg shedding were performed for all available herds, treated or not, in attempting to assess snail habitat-related risk.

Size of farm and stochastic effects of the distribution of moist areas within the HM soils may also be important. A small farm that by chance encompasses a broad slough may be at high risk (e.g.: farm 3J in this study), while another farm may have a large

proportion of HM soils which hold little wet ground (e.g.: farm 2B). As farm sizes increase, the proportions occupied by habitat could become smoothed, more stable. The relationship of areal extent of habitat to infection risk may then be stochastic, rather than determinant, with greater variance, particularly among small farms, than could be resolved by the small sample size of this study.

Correlation of *F. hepatica* and *P. microbothrioides* egg shedding - The egg shedding index accounts for both mean egg shedding rate and prevalence, reducing the effect of an occasional animal shedding high numbers of eggs in a herd of animals otherwise shedding low numbers, and may give a stabilized indicator of egg shedding intensity. The correlation in untreated herds of egg shedding indices for the 2 fluke species in August 1988 suggested that a relationship may exist, but they did not correlate in Fall 1987. The log transformed *F. hepatica* egg shedding rates were not significantly correlated with *P. microbothrioides* egg shedding rates.

Mean body condition and fecal egg shedding - The significant inverse relationship between body condition scores estimated in March 1989 and *P. microbothrioides* egg shedding in August 1988 and March 1989 may be due to snail-related habitat risk involving one or both fluke species. However, an alternative explanation, pending further work, is that worm burdens, levels of egg shedding and body condition scores may all co-vary with factors related to both snail habitat and management.

A trend of increased fecal shedding of paramphistome eggs was observed with increases in an index that includes extent of a habitat-prone soil type on 10 farms in these studies. However, this trend was not statistically significant. These results may ultimately be more useful if refined by more accurate measures of either habitat risk or herd infection rate. It seems likely that a photographic or remote sensing image of the area with spatial and spectral qualities permitting differentiation of the moist zones within HM soils on broad cheniers and along interfaces of broad chenier and marsh may also permit more accurate modeling of snail host habitat distribution, enhancing fit in a future model.

TABLE 1 - Summary herd data and fecal sedimentation statistics for 4 sample periods: fall 1987, June 1988, August 1988 and March 1989. Farms are ranked in order of increasing soil model index as of June 1988. Farm ID - Farm identification; Farm area; Pct HM Soil - per cent of farm comprised of soils of the Hackberry-Mermentau complex; No. cows - number of adult cows on pastures at time of sample collection; Soil model index - product of proportion of farm as Hackberry-Mermentau soil complex and no. of cows; Rx - Treatment history (+ recently treated with clorsulon, strategically targeted against mature F. hepatica from the previous transmission season so as to markedly reduce egg shedding at the time of sampling; - untreated; * treatment other than recently); fecal sedimentation results for P. microbothrioides (P. micro.) and F. hepatica (F. hep); Mean - mean egg count per 2g feces; Prev - Fecal egg shedding prevalence; Mean body cond - Mean body condition score, March 1989. (Continued on next page)

TIME	FARM ID	FARM AREA	PCT HM SOIL	No. COWS	SOIL MODEL INDEX	Rx	FECAL P. MEAN	SEDIMENTATION micro PREV	RESULTS F. hep. MEAN PREV	MEAN BODY COND	
FALL 1987	3H	67.4	0.0	21	0.0	+	0.1	0.1	0.1	0.1	ND
	2A	219.3	0.5	28	0.2	+	0.0	0.0	0.8	0.6	ND
	3A	68.6	1.2	30	0.4	-	3.9	0.9	2.5	0.7	ND
	3I	45.3	10.6	30	3.2	-	3.7	0.8	13.4	0.9	ND
	3G	47.0	14.2	40	5.7	-	5.7	0.9	6.9	0.7	ND
	3C	115.4	8.2	75	6.2	-	1.9	0.5	3.9	0.8	ND
	3J	14.7	51.6	22	ND	-	ND	ND	ND	ND	ND
	3B	23.5	58.2	22	12.8	-	2.8	0.9	4.3	0.8	ND
	3D	12.7	56.0	23	12.9	-	3.0	0.8	8.0	0.7	ND
	2B	82.0	23.7	80	19.0	*	10.2	0.7	12.4	0.8	ND
JUNE 1988	3H	67.4	0.0	21	0.0	+	1.8	0.4	0.1	0.1	ND
	2A	219.3	0.5	28	0.2	+	ND	ND	ND	ND	ND
	3A	68.6	1.2	30	0.4	-	16.3	1.0	3.7	0.9	ND
	3I	45.3	10.6	30	3.2	-	4.5	0.9	4.1	0.9	ND
	3G	47.0	14.2	30	4.3	+	5.8	0.8	0.2	0.1	ND
	3C	115.4	8.2	75	6.2	-	2.2	0.6	5.0	0.8	ND
	3J	14.7	51.6	22	11.3	*	9.3	0.8	4.6	0.7	ND
	3B	23.5	58.2	22	12.8	-	10.4	0.9	1.1	0.6	ND
	3D	12.7	56.0	23	12.9	-	6.5	1.0	2.7	0.8	ND
	2B	82.0	23.7	67	15.9	*	ND	ND	ND	ND	ND
AUG 1988	3H	67.4	0.0	21	0.0	*	0.4	0.4	7.6	0.9	ND
	2A	219.3	0.5	31	0.2	+	2.5	0.7	1.1	0.3	ND
	3A	68.6	1.2	35	0.4	-	25.3	1.0	23.8	0.8	ND
	3I	45.3	10.6	30	3.2	-	4.2	0.9	19.8	0.9	ND
	3G	47.0	14.2	30	4.3	*	11.1	0.9	2.1	0.6	ND
	3C	115.4	8.2	75	6.2	-	9.8	0.8	14.8	0.9	ND
	3J	14.7	51.6	22	11.3	*	9.1	0.8	8.1	0.7	ND
	3B	23.5	58.2	19	11.1	-	17.9	0.9	6.2	0.6	ND
	3D	12.7	56.0	22	12.3	-	35.9	1.0	61.9	1.0	ND
	2B	82.0	23.7	67	15.9	*	6.7	0.9	13.5	0.8	ND
MAR 1989	3H	67.4	0.0	ND	ND	ND	ND	ND	ND	ND	ND
	2A	219.3	0.5	31	0.2	+	1.2	0.5	0.0	0.0	6.6
	3A	68.6	1.2	40	0.5	-	9.9	0.8	12.1	0.8	2.9
	3I	45.3	10.6	29	3.1	-	7.9	0.9	3.2	0.6	5.4
	3G	47.0	14.2	29	4.1	+	2.5	0.9	7.3	0.8	4.8
	3C	115.4	8.2	ND	ND	ND	ND	ND	ND	ND	ND
	3J	14.7	51.6	20	10.3	+	5.5	0.6	0.8	0.3	4.2
	3B	23.5	58.2	20	11.6	-	16.8	0.9	14.5	0.9	4.8
	3D	12.7	56.0	18	10.1	-	22.8	1.0	3.5	0.8	3.2
	2B	82.0	23.7	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 2 - Regression analysis of log-transformed P. microbothrioides and F. hepatica egg shedding vs. soil model index (proportion of farm as HM complex of soils * no. of cows).

TIME	<u>P. microbothrioides</u>				<u>F. hepatica</u>			
	n	r ²	p > F	slope	n [†]	r ²	p > F	slope
Fall 1987	9	0.303	0.124	0.106	6	0.037	0.717	0.023
June 1988	8	0.155	0.335	0.076	6	0.515	0.108	-0.069
August 1988	10	0.184	0.216	0.099	9	0.008	0.818	0.019
March 1989	6	0.154	0.384	0.095	3	N/A	N/A	N/A
Fall 1989	5	N/A	N/A	N/A	3	N/A	N/A	N/A

[†] Data from herds recently treated with clorsulon, strategically targeted against mature F. hepatica from the previous transmission season so as to markedly reduce egg shedding at the time of sampling, were eliminated from analyses involving F. hepatica egg shedding.

TABLE 3 - Results of regression analyses of F. hepatica egg shedding index (mean EP2G * prevalence) and log transformed F. hepatica egg shedding rates versus P. microbothrioides egg shedding index for 4 sampling periods.

TIME	n [*]	<u>F. hepatica</u>			Mean log <u>F. hepatica</u>		
		<u>egg shedding index</u>			<u>egg shedding</u>		
		r ²	p > F	slope	r ²	p > F	slope
Fall 1987	6	0.002	0.938	0.110	0.052	0.664	-0.099
June 1988	6	0.057	0.647	-1.231	0.004	0.906	-0.006
August 1988	9	0.586	0.016	1.231	0.271	0.151	0.053
March 1989	4	N/A	N/A	N/A	N/A	N/A	N/A

* Data from herds recently treated with clorsulon, strategically targeted against mature F. hepatica from the previous transmission season so as to markedly reduce egg shedding at the time of sampling, were eliminated from analyses involving F. hepatica egg shedding.

TABLE 4 - Mean body condition in March 1989 vs. egg shedding rates for P. microbothrioides and F. hepatica at 4 sampling periods. a) mean body condition vs. mean EP2G; b) mean body condition vs. egg shedding indices.

a. Mean body condition vs. mean egg shedding rates.

TIME	<u>P. microbothrioides</u>				<u>F. hepatica</u>			
	n	r ²	p > F	slope	n*	r ²	p > F	slope
Fall 1987	6	0.274	0.286	-0.388	5	N/A	N/A	N/A
June 1988	6	0.383	0.190	-0.140	5	N/A	N/A	N/A
August 1988	7	0.717	0.016	-0.090	6	0.388	0.186	-0.027
<u>March 1989</u>	<u>7</u>	<u>0.676</u>	<u>0.023</u>	<u>-0.131</u>	<u>3</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>

b. Mean body condition vs. egg shedding indices.

TIME	<u>P. microbothrioides</u>				<u>F. hepatica</u>			
	n	r ²	p > F	slope	n*	r ²	p > F	slope
Fall 1987	6	0.228	0.339	-0.383	5	N/A	N/A	N/A
June 1988	6	0.467	0.134	-0.147	5	N/A	N/A	N/A
August 1988	7	0.702	0.019	-0.086	5	N/A	N/A	N/A
<u>March 1989</u>	<u>7</u>	<u>0.583</u>	<u>0.046</u>	<u>-0.123</u>	<u>3</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>

* Data from herds recently treated with clorsulon, strategically targeted against mature F. hepatica from the previous transmission season so as to markedly reduce egg shedding at the time of sampling, were eliminated from analyses involving F. hepatica egg shedding.

Fig 1- P. microbothrioides (P. micro.) (a) and F. hepatica (b) EP2G indices (EP2G * prevalence) vs. rank farm soil model index (area of HM soils * no. of cows / area of farm). Treatment history is indicated by + (recently treated herd [received an effective flukeicide at a time expected to produce a marked reduction in egg shedding at the time of sample collection; for the fall 1987 sample period, treated after May 1987; for the June 1988 sample period treated after March 1988; for the August 1988 sample period treated after May 1988; and for the March 1989 sample treated after June 1988]; - (history of no flukeicide treatment); * (flukeicide treatment history, not recent); N (no fecal sedimentation or body condition data).

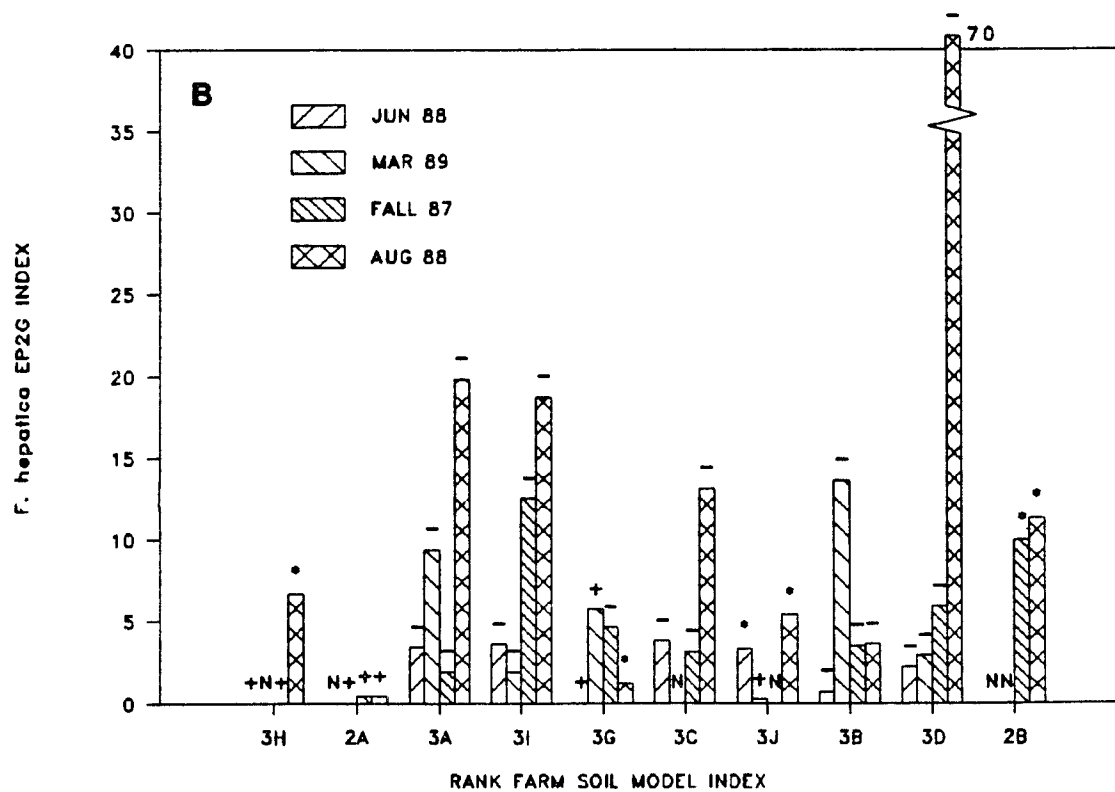
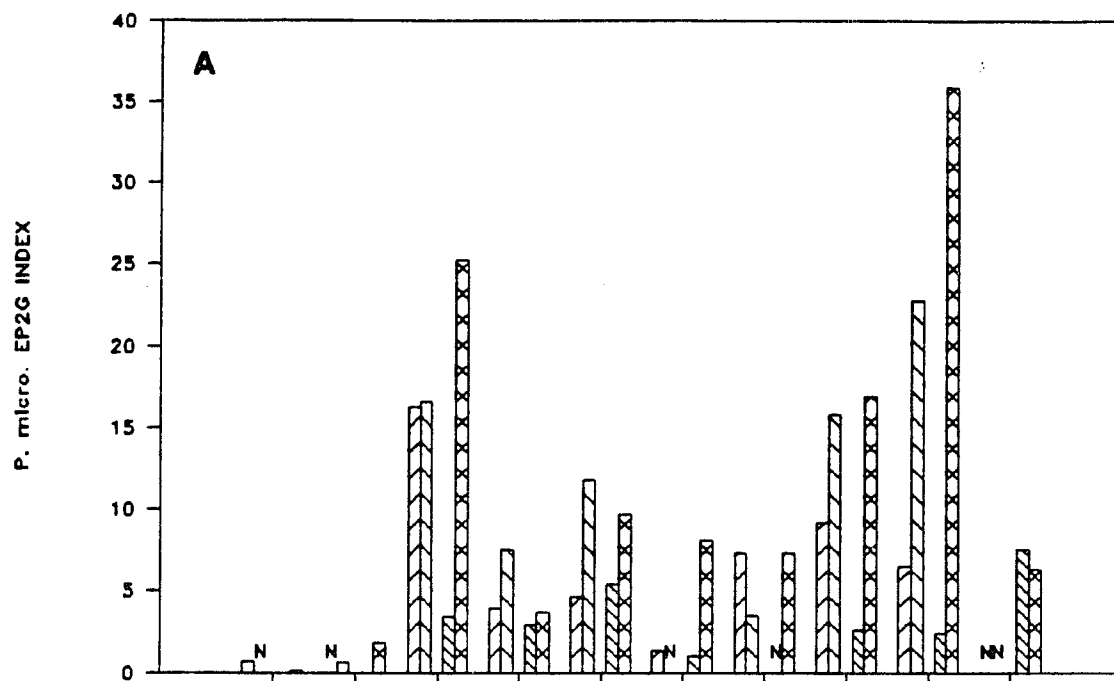
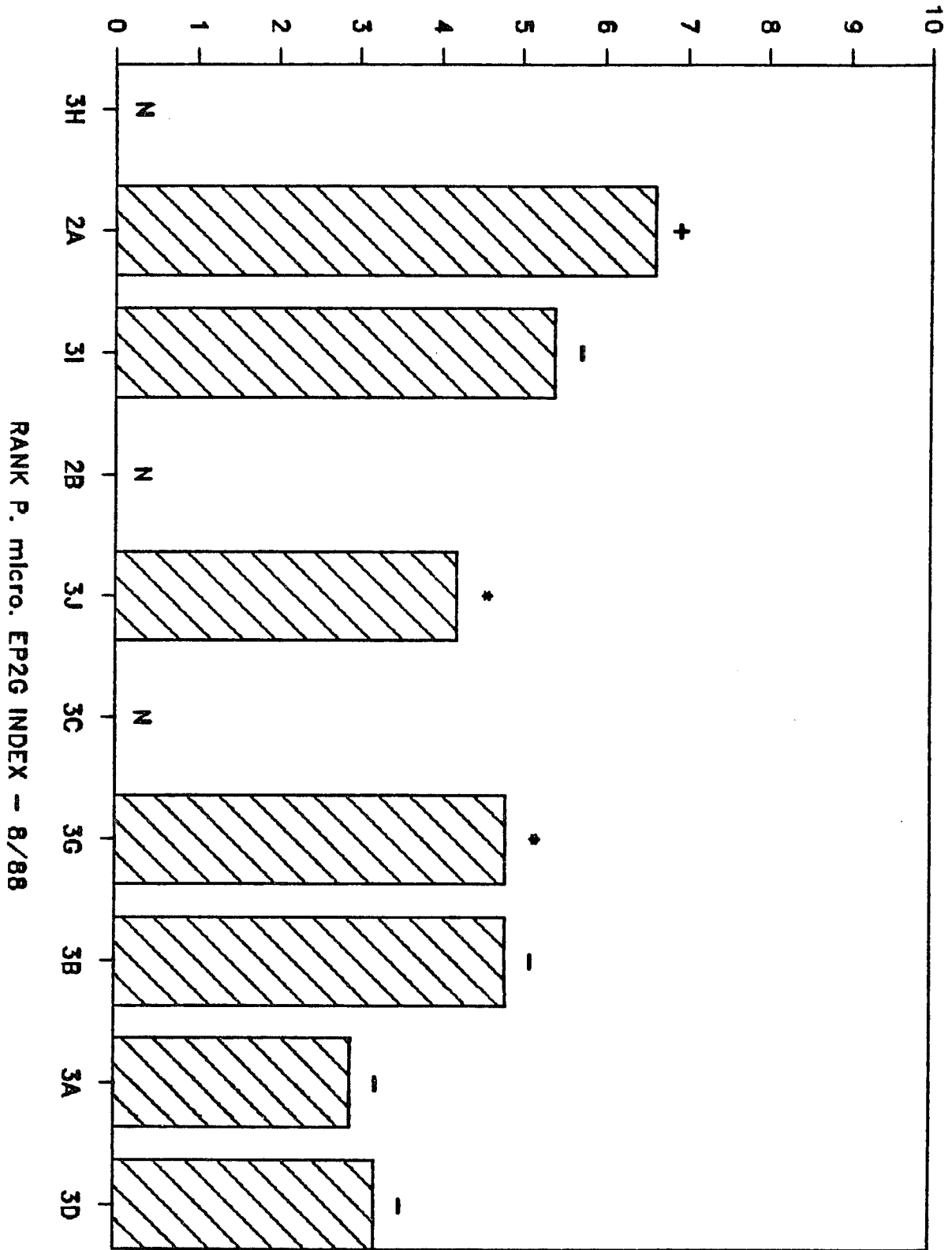


Fig 2- Mean body condition estimated in March 1989 (scale of 1 to 10) vs. rank farm P. microbothrioides (P. micro) EP2G in August 1988. Treatment history is indicated by + (recently treated herd [received an effective flukeicide at a time expected to produce a marked reduction in egg shedding at the time of sample collection; for the fall 1987 sample period, treated after May 1987; for the June 1988 sample period treated after March 1988; for the August 1988 sample period treated after May 1988; and for the March 1989 sample treated after June 1988]; - (history of no flukeicide treatment); * (flukeicide treatment history, not recent); N (no fecal sedimentation or body condition data).

MEAN BODY CONDITION - 3/89



From the Department of Veterinary Microbiology and
Parasitology, Louisiana State University, Baton Rouge, LA 70803.

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FOOTNOTES

^aZukowski, SH. 1990. Fasciola hepatica: Use of Soil Maps in a Geographic Information System to Indicate Snail Host Habitat Distribution on Louisiana Coastal Ranges. Ph.D. Thesis, Louisiana State University.

^bCuratrem. Merck & Co., Inc., Rahway, New Jersey.

^cFlukefinder. Flukefinder, Moscow, Idaho.

^dSAS System. SAS Institute Inc., Cary, North Carolina.

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CURRICULUM VITAE

STANLEY HARLAND ZUKOWSKI

PERSONAL DATA:

Born: November 19, 1950; Hyannis, Massachusetts

Married: January 11, 1978 Mary Louise Thompson
New York, New York

Children: Jennifer Marian June 4, 1981
Amy Louise September 18, 1983
Michael Ransford September 18, 1983
Joseph Arthur May 4, 1987
Robert Louis May 4, 1987

HIGHER EDUCATION:

Bachelor of Science - General Studies, United States Coast
Guard Academy, 1973

Pre-veterinary studies - University of New Orleans,
1978 - 1980

Doctor of Veterinary Medicine - School of Veterinary
Medicine, Louisiana State University, 1984

Doctor of Philosophy - School of Veterinary Medicine,
Louisiana State University (anticipated completion
August 1990).

MAJOR FIELD: Veterinary Medical Sciences; emphasis on ecological
parasitology, vector biology, host-parasite interactions,
detection and epidemiologic assessment of parasitic infections.

DISSERTATION: A Geographic Information System for Risk
Assessment of Fasciola hepatica in Cattle.

MAJOR PROFESSOR: J.B. Malone, Jr., D.V.M., Ph.D.

MINOR FIELD: Geography; emphasis on application of geographic
information systems, remote sensing and spatial analysis to
vector ecology and epidemiology of parasitic disease.

RESEARCH INTERESTS:

Zoogeography of parasitic disease. Vector ecology, host-
parasitic relationship, detection of infection,
epidemiologic assessment, disease control.

ACADEMIC AND PROFESSIONAL APPOINTMENTS:

September 1985 - present: Graduate Assistant, Department of Veterinary Microbiology and Parasitology, Louisiana State University

July 1984 - September 1985: Research Associate, Department of Veterinary Microbiology and Parasitology, Louisiana State University

PROFESSIONAL ORGANIZATIONS:

American Veterinary Medical Association

American Society of Tropical Medicine and Hygiene

American Association of Veterinary Parasitologists

American Society for Photogrammetry and Remote Sensing

World Association for the Advancement of Veterinary Parasitology

Phi Zeta Society

American Public Health Association

HONORS:

President, Louisiana State University Chapter, American Society for Photogrammetry and Remote Sensing, 1987-88

Louisiana State University Veterinary Medical Summer Student Research Honors Program, 1982

PROFESSIONAL LICENSES:

South Carolina Board of Veterinary Medical Examiners (1985)

Louisiana Board of Veterinary Medicine (1985)

MILITARY SERVICE:

United States Coast Guard, Lieutenant (junior grade), 1973 - 1978. Assignments on ship and shore in Alaska, New York and New Orleans, the last chosen for the presence in the state of the School of Veterinary Medicine.

PUBLISHED ABSTRACTS:

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Zukowski, S.H., J.B. Malone, and J.M. Hill III. Use of a computerized geographic system to model potential habitat of Fossaria bulimoides, a snail host of Fasciola hepatica. 36th Annual Meeting of the American Society of Tropical Medicine and Hygiene, Los Angeles, CA, November 29 - December 4, 1987.

Zukowski, S.H., J.B. Malone, and J.M. Hill III. Use of a computerized geographical information system to model potential habitat of Fossaria bulimoides on coastal marsh pasture in Louisiana. Annual Meeting of the American Association of Veterinary Parasitologists, Portland, OR, July 17-18, 1988.

Zukowski, S.H., J.B. Malone, J.M. Hill and F.W. Jones. Use of a Geographic Information System to develop a soil-based model for transmission of fluke disease in cattle. International Conference on Applications of Remote Sensing to Epidemiology and Parasitology, Baton Rouge, LA, June 6-7, 1990.

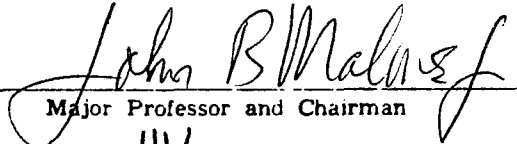
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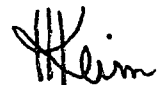
Candidate: Stanley H. Zukowski

Major Field: Veterinary Medical Sciences

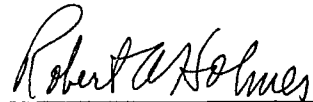
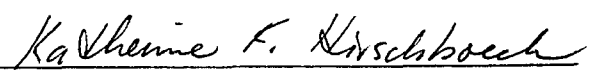
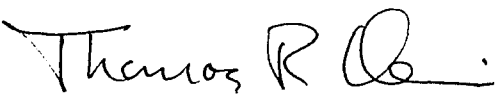

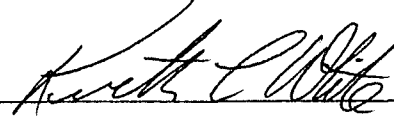
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Approved:


Major Professor and Chairman


Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

6/27/90